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Smoke Management Photographic Guide: A Visual Aid for Communicating Impacts

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Abstract

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Communicating emissions impacts to the public can sometimes be difficult because quantitatively conveying smoke concentrations is complicated. Regulators and land managers often refer to particulate-matter concentrations in micrograms per cubic meter, but this may not be intuitive or meaningful to everyone. The primary purpose of this guide is to serve as a tool for communicating potential particulate matter ($PM_{2.5}$) levels during wildfire events using visual representation. Examples of visibility impairment under various levels of smoke concentration and humidity have been modeled using the WinHaze program.

Keywords: Air quality, regional haze, smoke management.

Contents

Introduction

An important but difficult part of determining the impacts of emissions from wildland fire on air quality is the preparation of a quantitative smoke-concentration assessment. Although smoke is composed of a variety of chemical compounds and other components, regulators and land managers often focus on particulate matter (PM) owing to its effects on human health and visibility degradation. Particulate matter in smoke generally ranges from 0.1 to 100 micrometers (μm) in diameter (Hardy et al. 2001). Diameters ≤10 μm (PM_{10}) and ≤2.5 μm ($PM_{2.5}$) are the most common size classes used in air quality measurement and monitoring. Particulate matter concentration is measured in units of micrograms per cubic meter ($\mu g/m^3$).

This guide will help air quality regulators and land managers communicate $PM_{2.5}$ concentrations during wildland fires.

Visibility is affected by several factors, including the composition and concentration of smoke from fires. Particulate matter emitted from fires can contain ammonium nitrate, ammonium sulfate, and light-absorbing carbon (Malm et al. 1994). The effect these compounds have on visibility can be magnified by increases in relative humidity, which causes more water vapor to adhere to particles thereby altering the way they absorb and reflect light (Malm et al. 2003). In addition, background levels of visibility vary geographically (Hand et al. 2014, Malm et al. 1994).

This guide illustrates the effects of wildland fire smoke on visibility for the continental United States (fig. 1). It was developed with images from locations in national parks and other scenic areas to assess visibility impairment associated with elevated $PM_{2.5}$ concentration through visual representation. Images presented in this guide were generated using WinHaze (Air Resource Specialists, Inc. 2013), a software tool developed to visualize the impacts of pollution on visibility.[1] Because of the complex relationships that influence observed visual range approximations—contrasts perceived by the naked eye, the effects of these contrasts on perception of visual range, and the effects of both of these factors on particle-concentration estimates—they should be used as general indicators, not precise measurements.

Methods

This reference guide was generated using WinHaze imaging software version 2.9.9.1. (Air Resource Specialists, Inc. 2013) for the purpose of representing visual impacts from smoke in numerous U.S. locations. To determine the reduction in visibility, WinHaze incorporates several years of particulate monitoring data and images from national parks and wilderness areas into a beta extinction equation

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Northern (Region 1): Selway-Bitterroot Wilderness (south), Glacier National Park (north)

Intermountain (Region 2): Rocky Mountain National Park

Southwestern (Region 3): Grand Canyon National Park (both)

Rocky Mountain (Region 4): Canyonlands National Park (east), Great Basin National Park (west)

Pacific Southwest (Region 5): Yosemite National Park

Pacific Northwest (Region 6): Columbia River Gorge National Scenic Area (south), Snoqualmie Pass (north)

Southern (Region 8): Great Smoky Mountains National Park (east), Mammoth Cave National Park (center), Big Bend National Park (west)

Eastern (Region 9): Acadia National Park

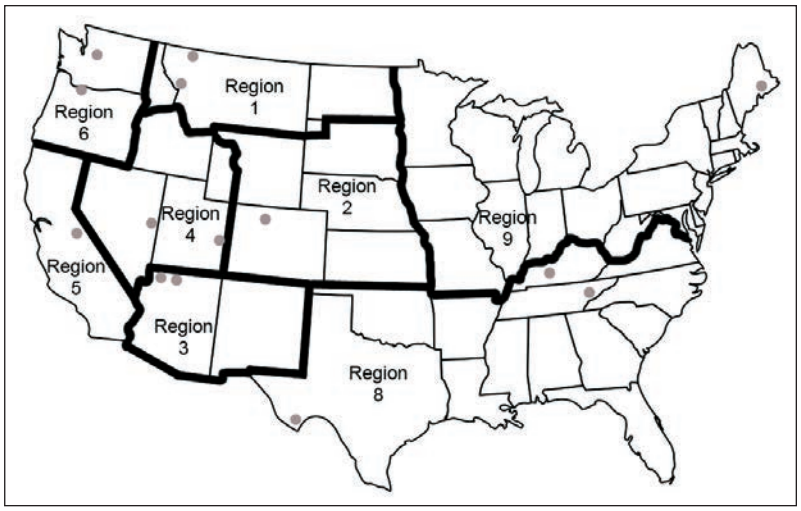

Figure 1—Locations of sites where estimations of decreased visibility were converted into photo images (grey dots). The sites selected represent typical conditions in each of the National Forest System regions of the contiguous U.S. states.

(Hand and Malm 2006); the equation, images, and data are products of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program, which has placed stationary cameras and air quality monitoring equipment at several national parks (http://vista.cira.colostate.edu/improve/Default.htm. [15 June 2015]).

WinHaze allows for consistent visual representation of air quality under varying levels of humidity, background pollution, and $PM_{2.5}$ concentration. Each example in this guide presents a simulated baseline image that represents the visual range under average PM concentrations juxtaposed with several images of simulated visual impairment. Visual impairment from smoke was simulated first by establishing constant values for the $PM_{2.5}$ constituents that would be unlikely to change with the introduction of smoke from fires; values for ammonium sulfate, ammonium nitrate, and fine soil were calculated by averaging the 20 percent worst visibility days. Organic carbon and black carbon—which account for nearly 75 percent of the emissions from forest fires (Andreae and Merlet 2001)—were then increased to reflect increasing concentrations of smoke using an organic-carbon to black-carbon ratio of 15.4:1 (Andreae and Merlet 2001). The coarse particulate inputs used to simulate each image were chosen based on the larger of two values: either the average value of the 20 percent worst monitored days, or 10 percent of the $PM_{2.5}$ (ammonium sulfate, ammonium nitrate, fine soil, organic carbon, and black carbon) concentration (Ward and Hardy 1991).

The version of WinHaze used for this work includes the first version of the IMPROVE beta extinction equation, as described in Hand and Malm (2006). To

improve the accuracy of the simulations by accounting for hygroscopicity (Malm et al. 2005)—the ability of a substance to attract and hold water molecules from the surrounding environment—a correction factor was applied to the organic carbon values before each image and visual range determination was generated; accordingly, light scattering (total beta extinction) of organic carbon increased linearly by a factor of 1.2 at 80-percent relative humidity compared to no relative humidity. Each image includes prominent landmarks with which to judge visual range. The distance between the camera locations and each landmark was measured with Google Earth and verified using location information from Air Resource Specialists, Inc.

Relative humidity affects visibility and changes throughout the day and from one season to the next; therefore, a range of values was chosen to represent morning and afternoon monthly averages most likely to occur during the wildland fire season (May to September) in all national park and wilderness-area locations (EPA 2014). Because these data were unavailable for the two Pacific Northwest (Region 6) locations (fig. 1), meteorological station data were chosen from a location as geographically close to the available site as possible (NOAA 2014).

Lipsett et al. (2012) and the Environmental Protection Agency (EPA 2013) define five levels for air quality: good, moderate, unhealthy for sensitive groups, unhealthy, and very unhealthy (table 1). These levels correspond to thresholds for action by public health officials: good requires no action, moderate suggests sensitive populations reduce prolonged or heavy exertion, unhealthy for sensitive groups requires warnings or alerts to those with heart or lung conditions or other pertinent health issues, unhealthy requires that all people should be notified, regardless of health status, and very unhealthy recommends everyone should avoid physical activity outdoors (Lipsett et al. 2012). The $PM_{2.5}$ levels that were chosen for display in this guide were good (<38 μg/m^3), unhealthy for sensitive groups (89 to 138 μg/m^3), and unhealthy (139 to 351 μg/m^3) for a short period of time (up to 3 hours) because they are sufficiently different as to be easily discernable to the naked eye. The mid-point of each range was chosen to represent each health level: 19 μg/m^3 for good, 114 μg/m^3 for unhealthy for sensitive groups, and 245 μg/m^3 for unhealthy.

Each set of images includes tables documenting the constituents of particulate matter (PM) at different concentration levels, and visual range at different relative humidity and PM concentrations levels.

Public health officials may recommend different actions based on the concentration of smoke in the area.

Using This Guide

Each set of images in this guide is preceded by a description of the air quality data for the site depicted, including the date range and number of sampling days of PM data used by WinHaze, the source for the relative humidity data, a table listing the constituents of smoke (both $PM_{2.5}$ and PM_{10}) represented in the images, and a table

Table 1—Images and visual range estimates representing the particulate matter (PM) concentration mid-points of the good (19 µg/m^3), unhealthy for sensitive groups (114 µg/m^3), and unhealthy (245 µg/m^3) categories were chosen for display in this guide

Air quality	PM_{10} or $PM_{2.5}$ concentration (µg/m^3) [a] [b]	Actions required to protect health
Good	0 to 38	- No action needed.
Moderate	39 to 88	- Unusually sensitive people should consider **reducing** prolonged or heavy exertion.
Unhealthy for sensitive groups	89 to 138	- People with heart or lung disease, children, and older adults should **reduce** prolonged or heavy outdoor exertion. - Everyone else should **limit** prolonged or heavy exertion.
Unhealthy	139 to 351	- People with heart or lung disease, children, and older adults should **avoid** all physical activity outdoors. - Everyone else should **avoid** prolonged or heavy exertion.
Very unhealthy	>351	- People with heart or lung disease, children, and older adults should remain indoors and keep activity levels low. - Everyone else should **avoid** all physical activity outdoors.

[a] PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 µm and ≤2.5 µm in diameter, respectively.

[b] Concentrations are 1- to 3-hour averages.

Source: Adapted from Lipsett et al. (2012) and EPA (2013).

listing all of the visible range distances for each $PM_{2.5}$ concentration and relative humidity level.

To use this guide for visualizing $PM_{2.5}$ concentration, select the region and location that best matches the terrain and humidity conditions of the location you are assessing and compare your line-of-sight with landmarks located at distances that correspond to those shown in the photographs. Unless no distinction could be made between photographs, as sometimes occurs at the higher $PM_{2.5}$ concentration levels, images are included that represent baseline (smoke free), good (19 µg/m^3), unhealthy for sensitive groups (114 µg/m^3), and unhealthy (245 µg/m^3) conditions for each location.

Limitations

Visual range is simulated based on analyses of both air quality data and the constituents of wildland fire smoke. Images included in this guide were generated

independently of one factor (sun angle) that has an effect on visibility (Malm and Schichtel 2013, Middleton 1968). Also, the $PM_{2.5}$ concentration levels for good, unhealthy for sensitive groups, and unhealthy conditions shown in the photographs are not instantaneous "snapshots," but are based on average levels over a period of 1 to 3 hours. This is important because visual ranges can change relatively rapidly.

English Equivalents

When you know:	Multiply by:	To find:
Micrometers (μm)	0.039	Mils
Micrograms (μg)	0.00002	Grains
Kilometers (km)	0.62	Miles

Acknowledgments

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Appendix

Northern Region (National Forest System—Region 1):

Selway-Bitterroot Wilderness and Glacier National Park (Montana)

Particulate data from 1,037 days of sampling (March 1988 to May 1999) at Glacier National Park were chosen to represent baseline and elevated regional air quality concentrations (table 2). Table 3 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<5, 19, 114, and 245 μg/m^3) and relative humidity for both the Selway-Bitterroot Wilderness and Glacier National Park. The simulated images show a baseline representing an area free of smoke-impaired visibility (<5 μg/m^3 fine and coarse particulates) and two or three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Glacier National Park (EPA 2014).

Table 2—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<5 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in the Selway-Bitterroot Wilderness and Glacier National Park, Montana

Particulate matter constituents	Particulate matter concentration			
	<5 (Baseline)	19	114	245
		μg/m^3		
Ammonium sulfate	0.96	1.29	1.29	1.29
Ammonium nitrate	0.30	0.61	0.61	0.61
Organic carbon	2.67	14.95	104.14	227.13
Black carbon	0.43	0.97	6.78	14.79
Fine soil	0.58	1.19	1.19	1.19
Coarse mass	6.12	10.21	11.40	24.50

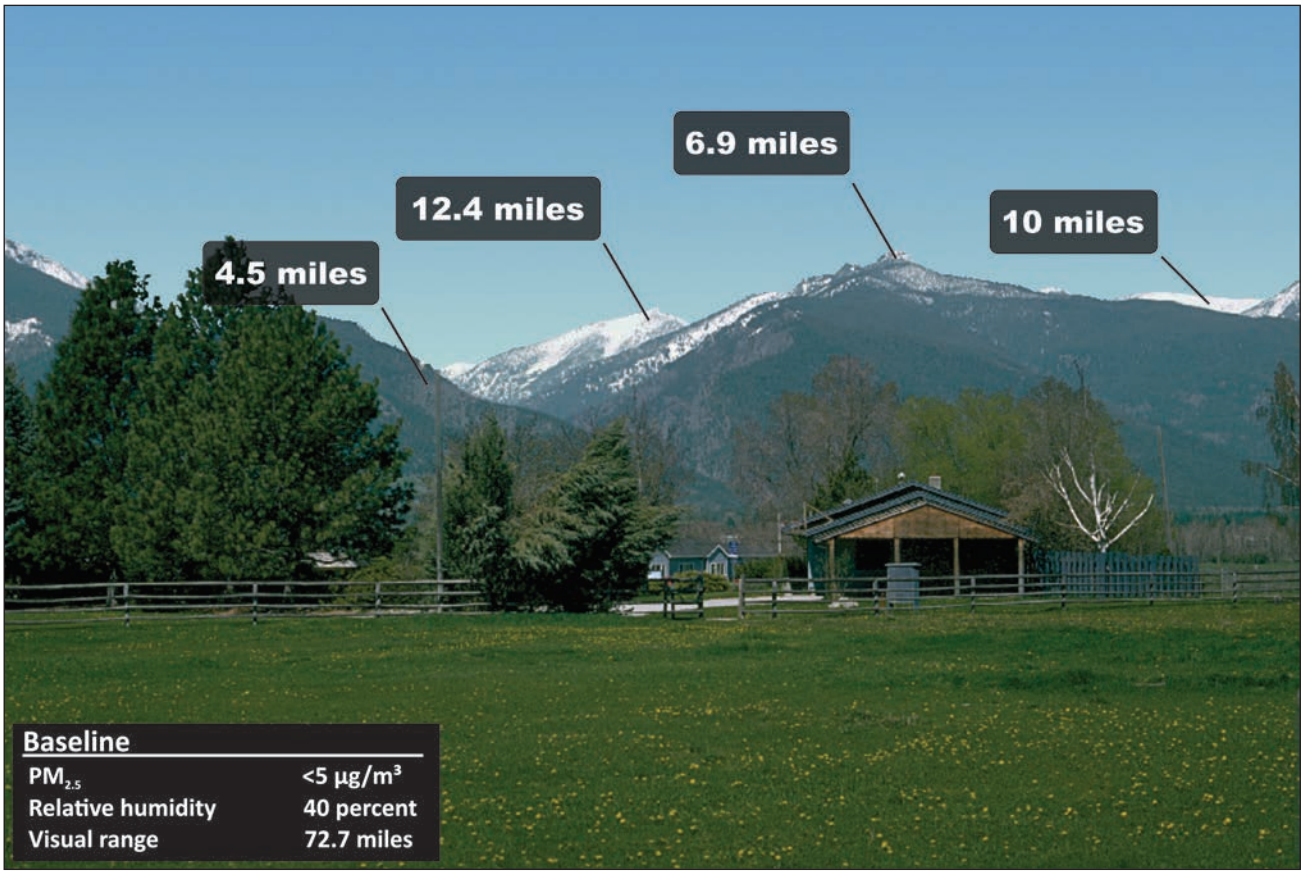
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

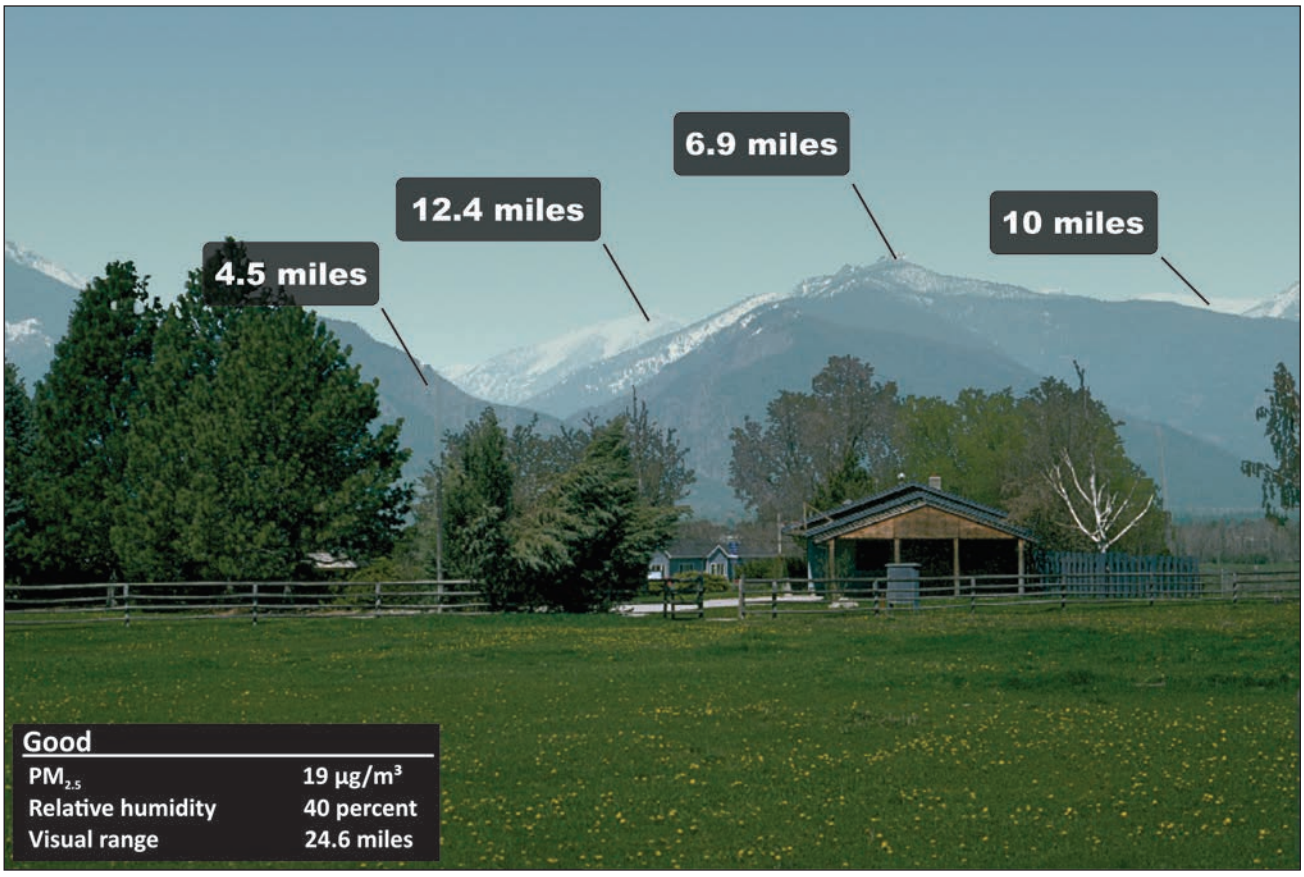
Table 3—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in the Selway-Bitterroot Wilderness and Glacier National Park, Montana

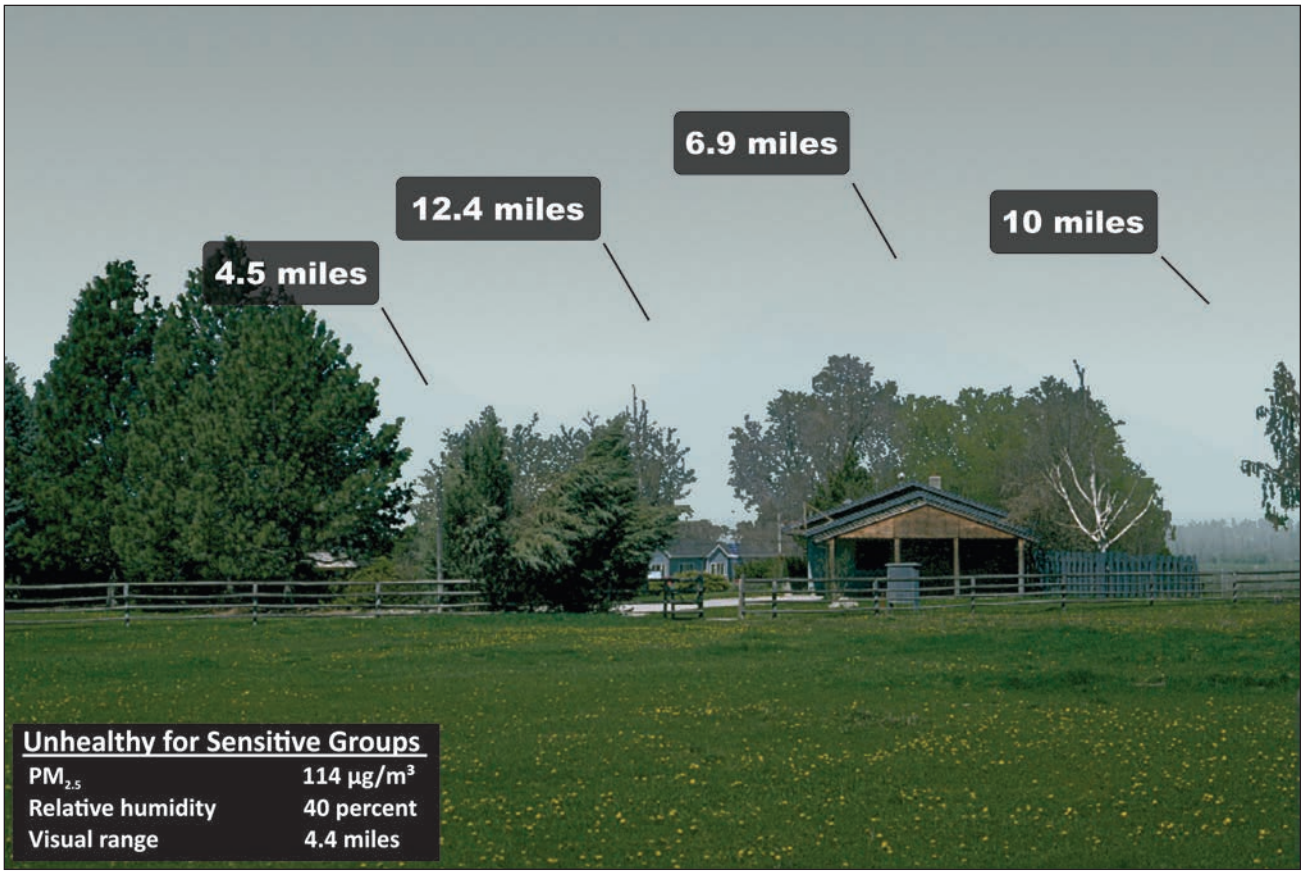
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<5 (Baseline)	40	72.7	117.0
19 (Good)	40	24.6	39.6
	60	23.1	37.2
	80	21.3	34.3
	90	19.9	32.1
114 (Unhealthy for Sensitive Groups)	40	4.4	7.1
	60	4.2	6.8
	80	4.0	6.5
	90	3.9	6.3
245 (Unhealthy)	40	2.1	3.3
	50 to 60	2.0	3.2
	70 to 90	1.9	3.1

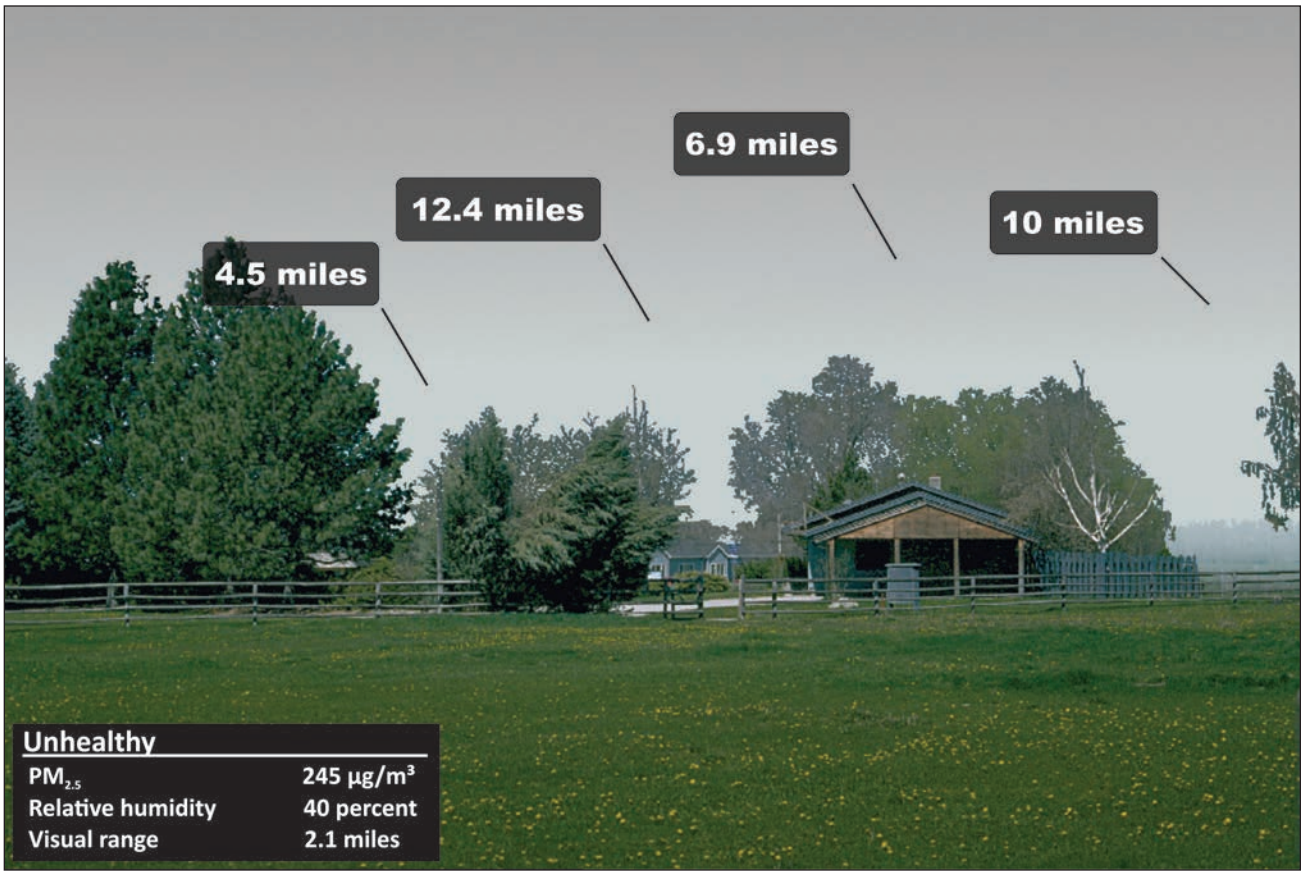
[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Selway-Bitterroot Wilderness (Montana)

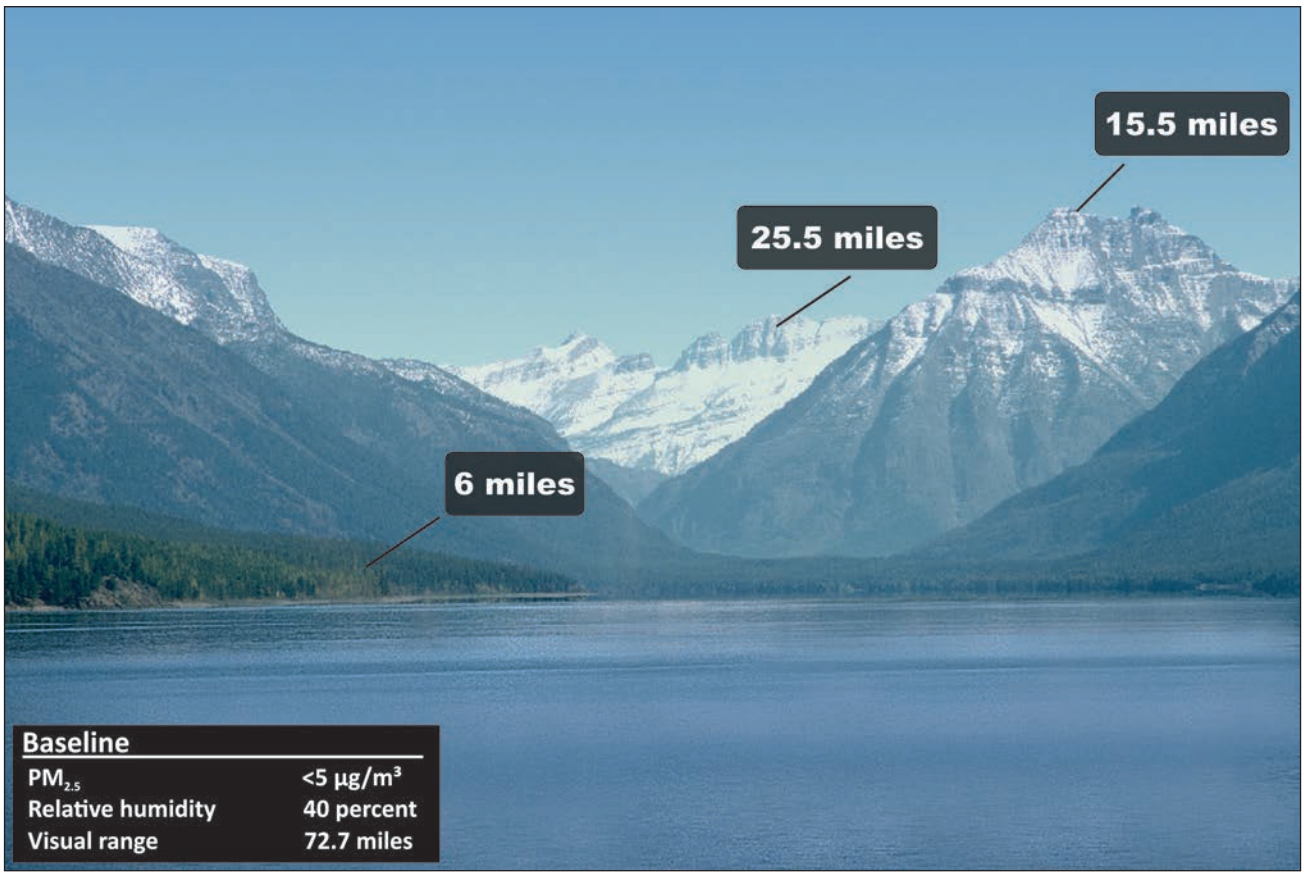


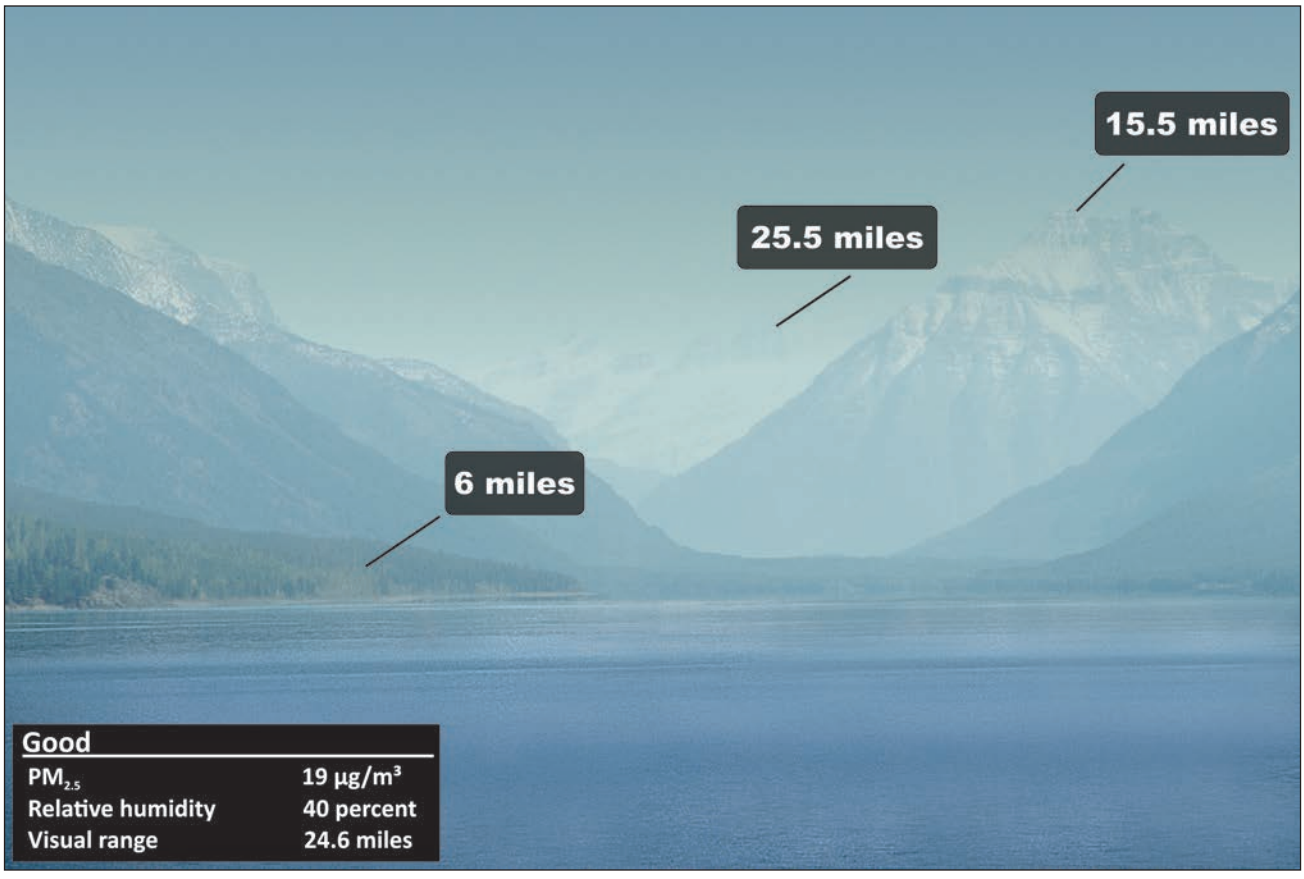


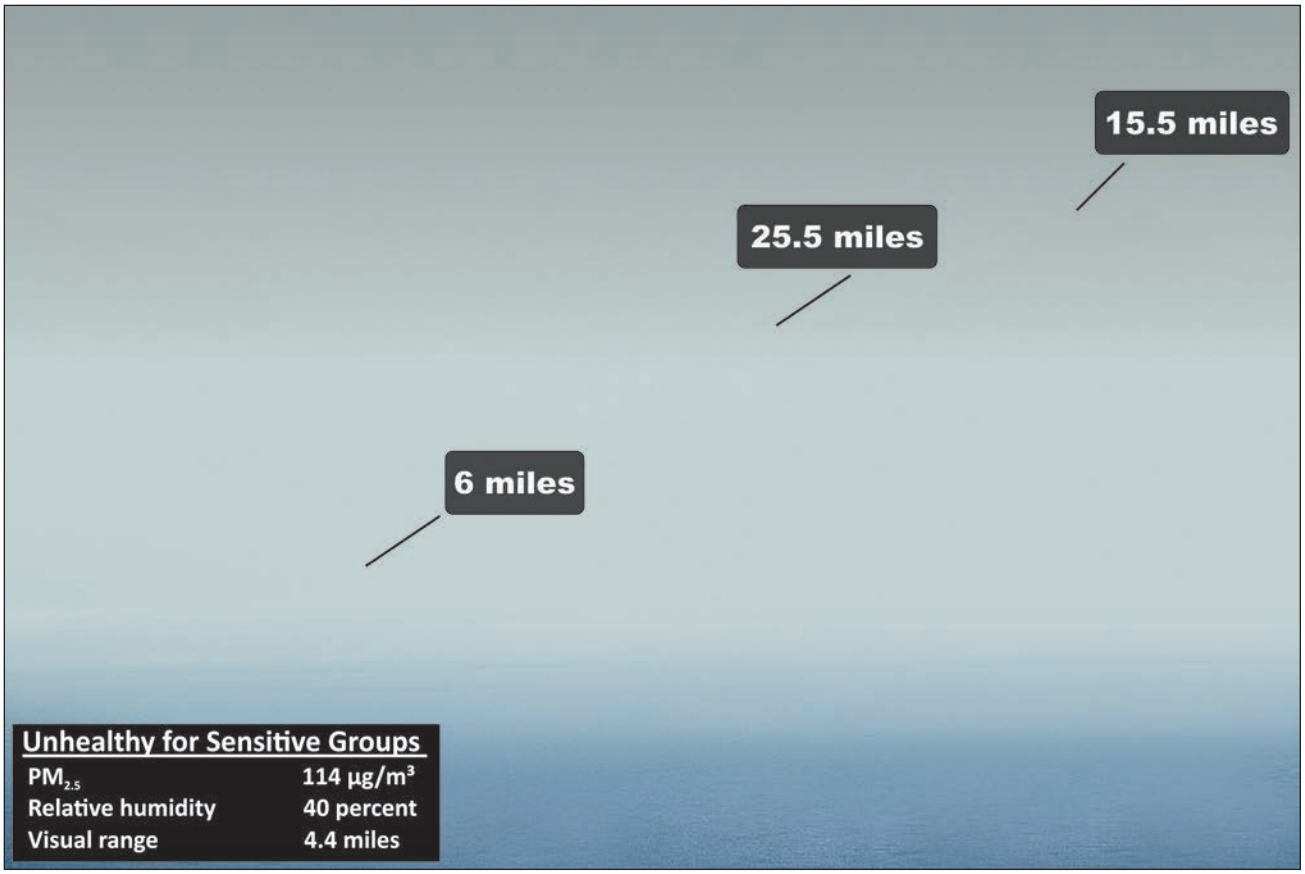

6.9 miles
12.4 miles
10 miles
4.5 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 40 percent
Visual range 4.4 miles


6.9 miles
12.4 miles
10 miles
4.5 miles
Unhealthy
PM2.5 245 µg/m³
Relative humidity 40 percent
Visual range 2.1 miles

Glacier National Park (Montana)






15.5 miles
25.5 miles
6 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m3
Relative humidity 40 percent
Visual range 4.4 miles

Intermountain Region (National Forest System—Region 2):

Rocky Mountain National Park (Colorado)

Particulate data from 794 days of sampling (September 1990 to May 1999) at Rocky Mountain National Park were chosen to represent baseline and elevated regional air quality concentrations (table 4). Table 5 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<5, 19, 114, and 245 μg/m^3) and relative humidity for Rocky Mountain National Park. The simulated images show a baseline representing an area free of smoke-impaired visibility (<5 μg/m^3 fine and coarse particulates) and three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Rocky Mountain National Park (EPA 2014).

Table 4—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at Baseline (<5 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Rocky Mountain National Park, Colorado

Particulate matter constituents	Particulate matter concentration			
	<5 (baseline)	19	114	245
		μg/m³		
Ammonium sulfate	0.93	1.49	1.49	1.49
Ammonium nitrate	0.29	0.50	0.50	0.50
Organic carbon	1.00	14.77	103.96	226.95
Black carbon	0.17	0.96	6.77	14.78
Fine soil	0.63	1.28	1.28	1.28
Coarse mass	3.96	5.88	11.40	24.50

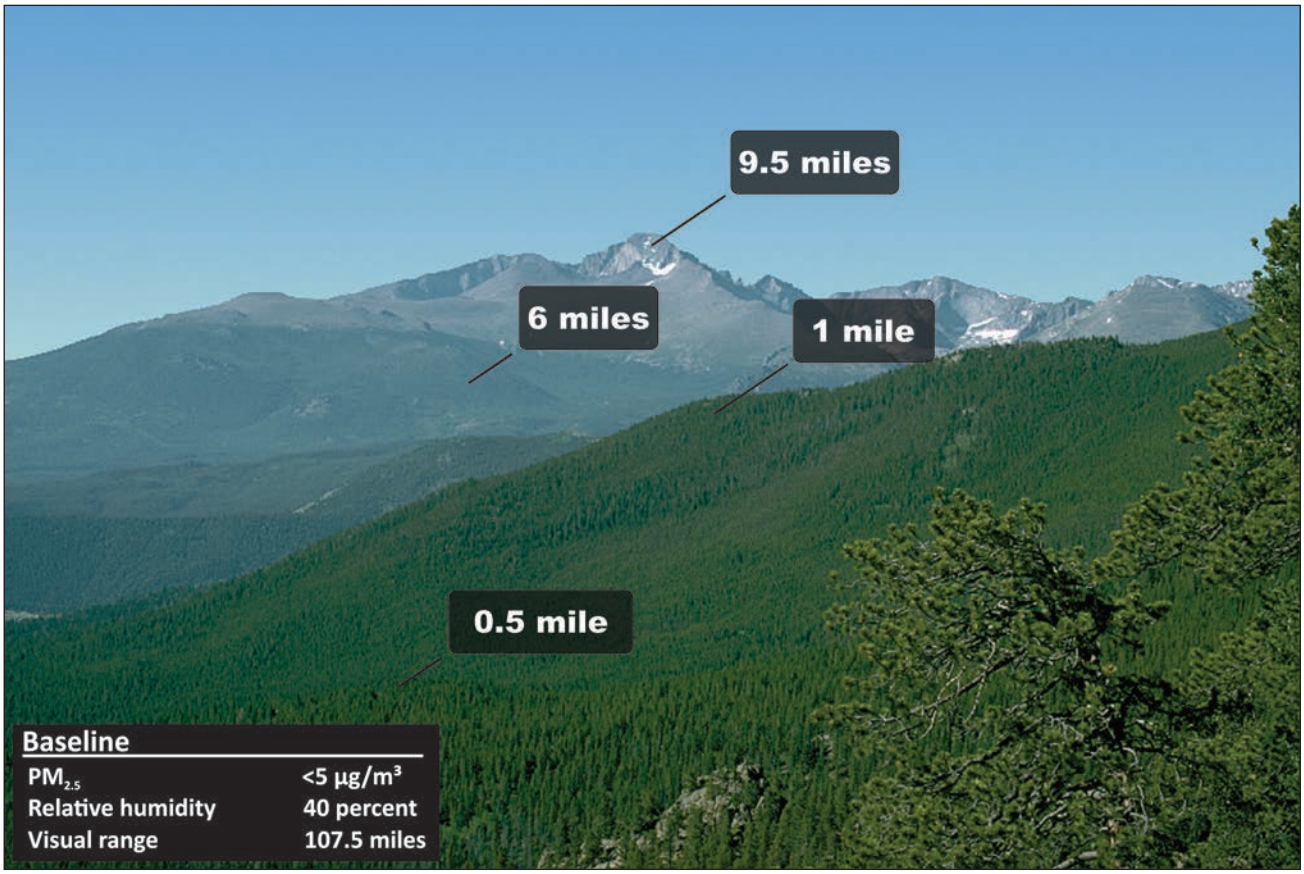
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

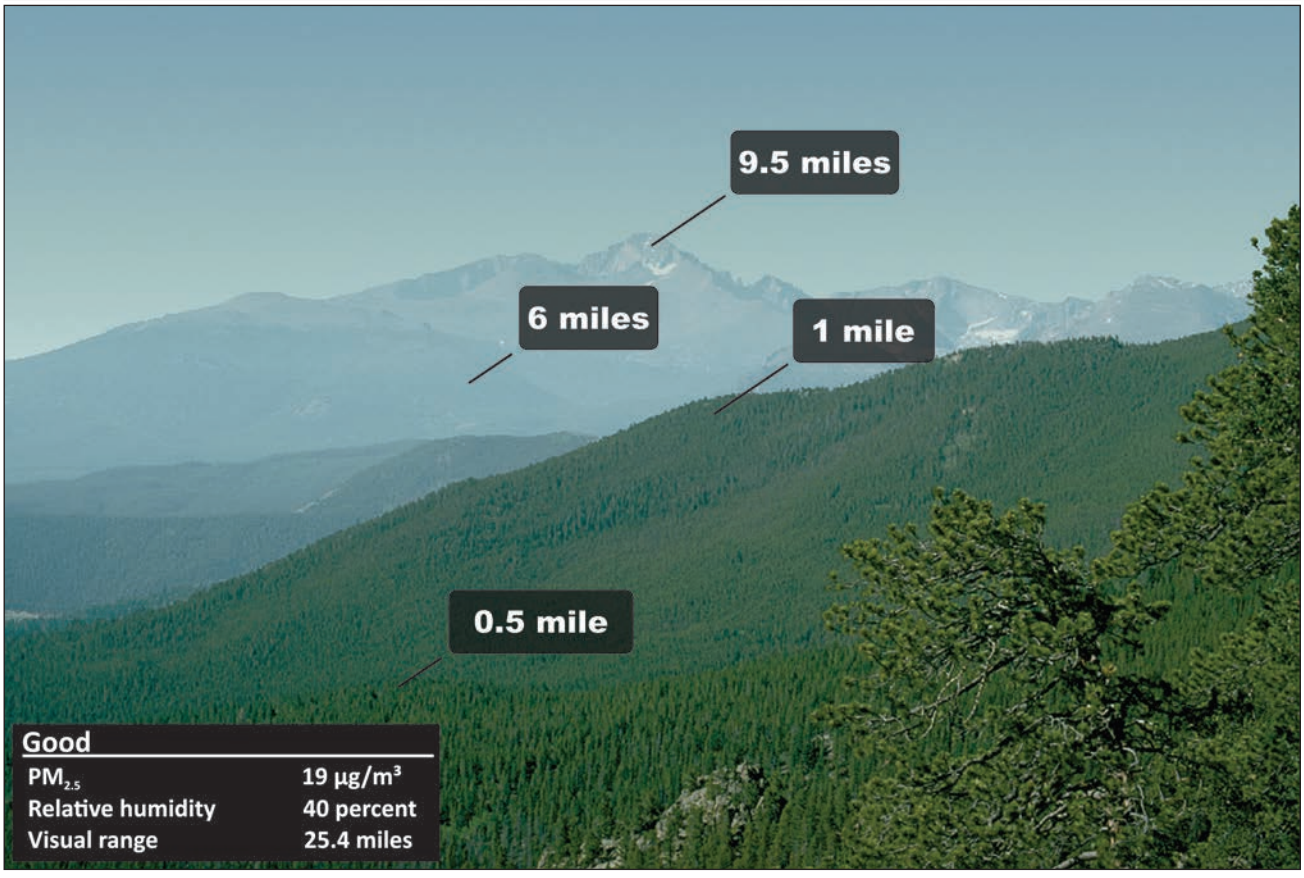
Table 5—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Rocky Mountain National Park, Colorado

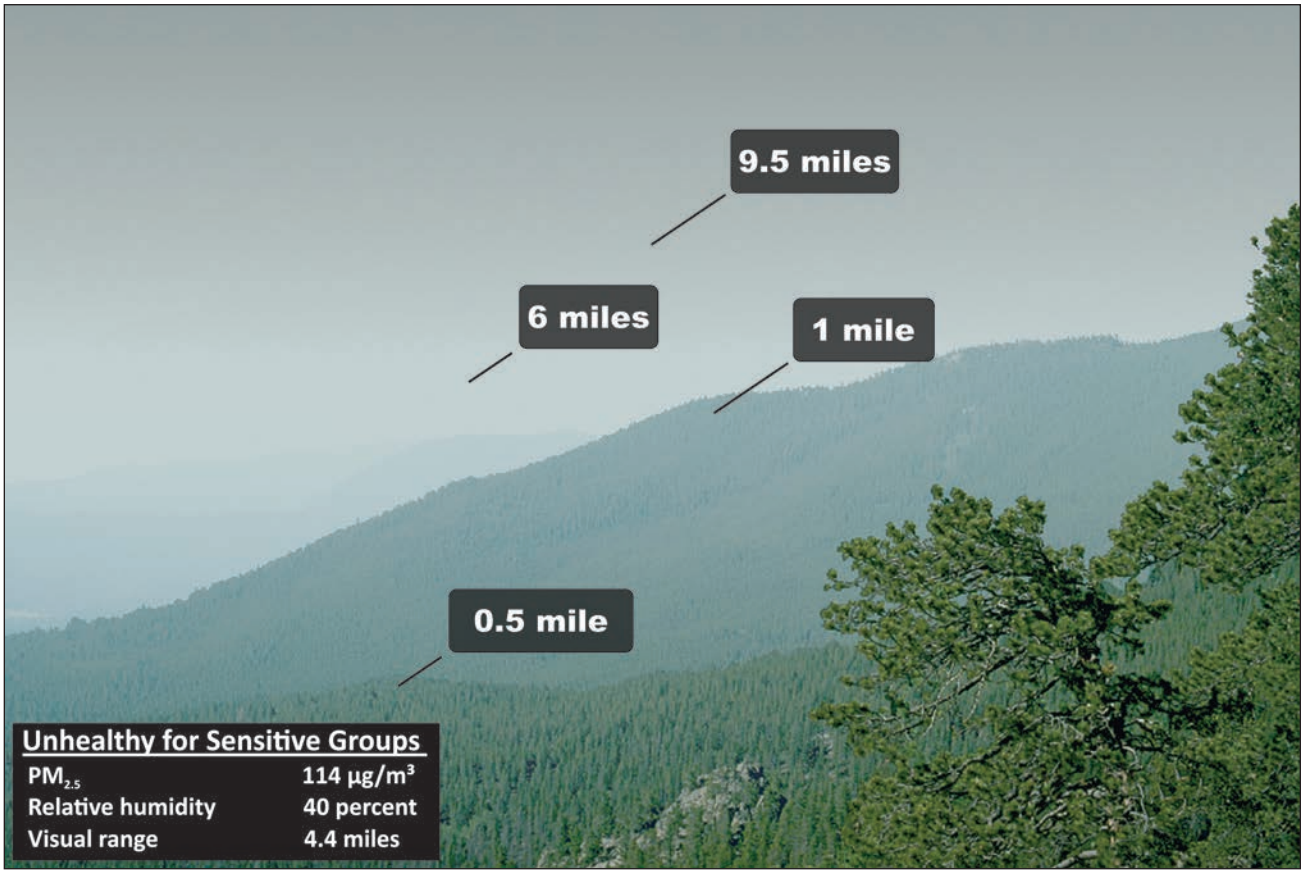
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<5 (Baseline)	40	107.5	173.0
19 (Good)	40	25.4	40.9
	50	24.6	39.6
	60	23.8	38.3
114 (Unhealthy for Sensitive Groups)	40	4.4	7.1
	50	4.3	7.0
	60	4.2	6.8
245 (Unhealthy)	40	2.1	3.3
	50 to 60	2.0	3.2

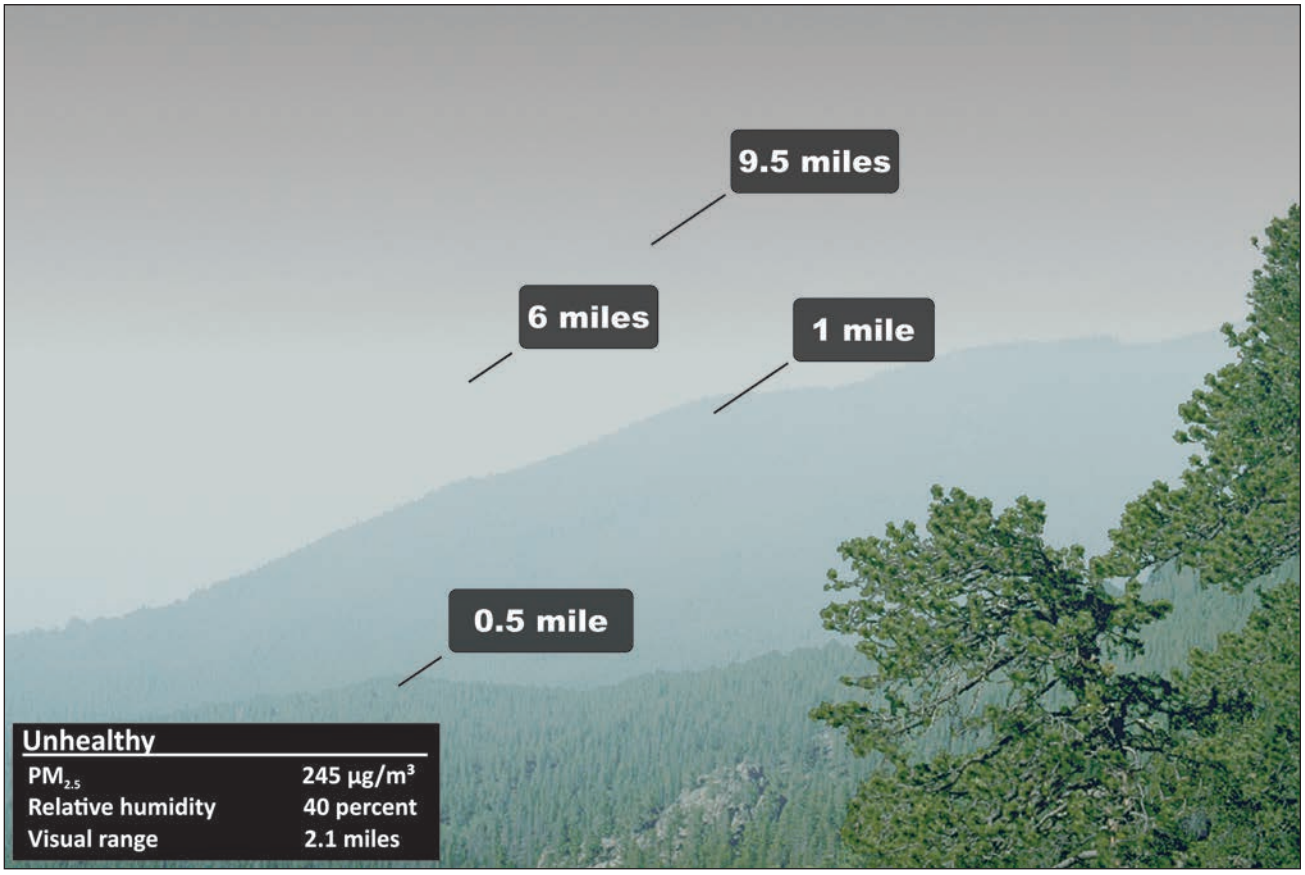
[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Rocky Mountain National Park (Colorado)






9.5 miles
6 miles
1 mile
0.5 mile
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 40 percent
Visual range 4.4 miles


9.5 miles
6 miles
1 mile
0.5 mile
Unhealthy
PM2.5 245 µg/m³
Relative humidity 40 percent
Visual range 2.1 miles

Southwestern Region (National Forest System—Region 3):

Grand Canyon National Park (Arizona)

Particulate data from 857 days (March 1988 to August 1998) at Grand Canyon National Park were chosen to represent baseline and elevated regional air quality concentrations (table 6). Table 7 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<3, 19, 114, and 245 μg/m^3) and relative humidity for two viewing locations at Grand Canyon National Park. The simulated images show a baseline representing an area free from smoke-impaired visibility (<3 μg/m^3 fine and coarse particulates) and two or three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Grand Canyon National Park (EPA 2014).

Table 6—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<3 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Grand Canyon National Park, Arizona

Particulate matter constituents	Particulate matter concentration			
	<3 (Baseline)	19	114	245
		μg/m^3		
Ammonium sulfate	1.01	1.59	1.59	1.59
Ammonium nitrate	0.20	0.31	0.31	0.31
Organic carbon	0.80	14.90	104.09	227.08
Black carbon	0.18	0.97	6.78	14.79
Fine soil	0.61	1.23	1.23	1.23
Coarse mass	4.99	7.16	11.40	24.50

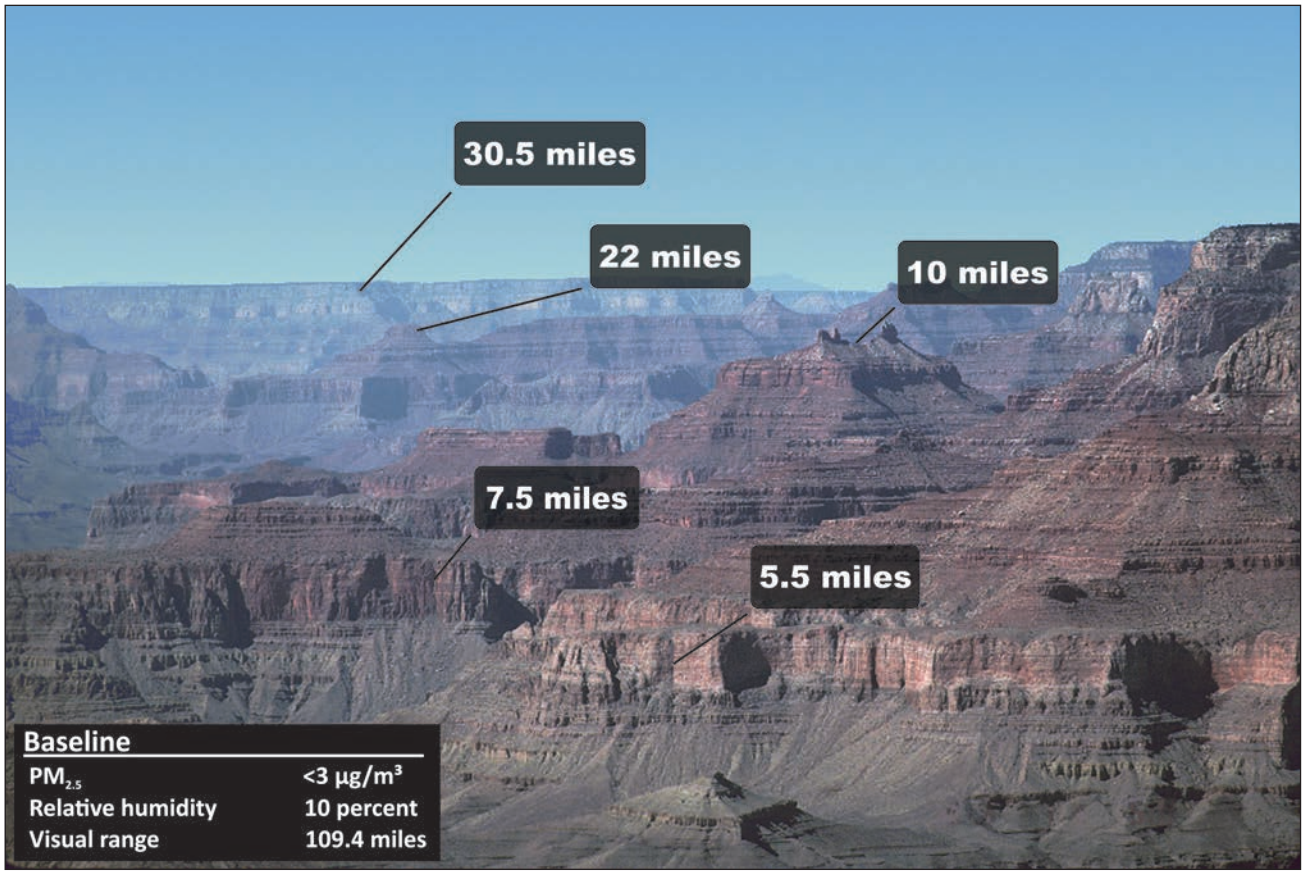
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

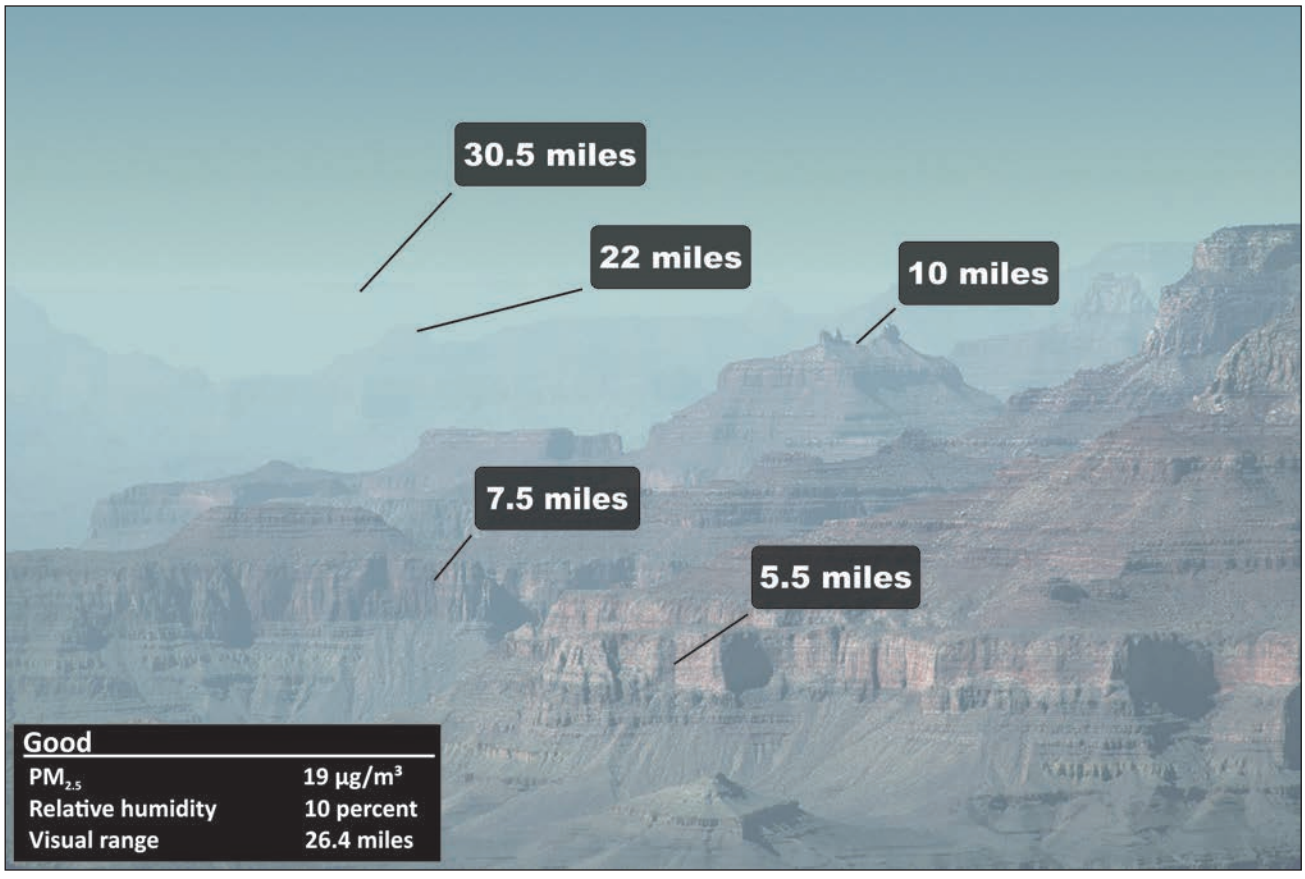
Table 7—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Grand Canyon National Park, Arizona

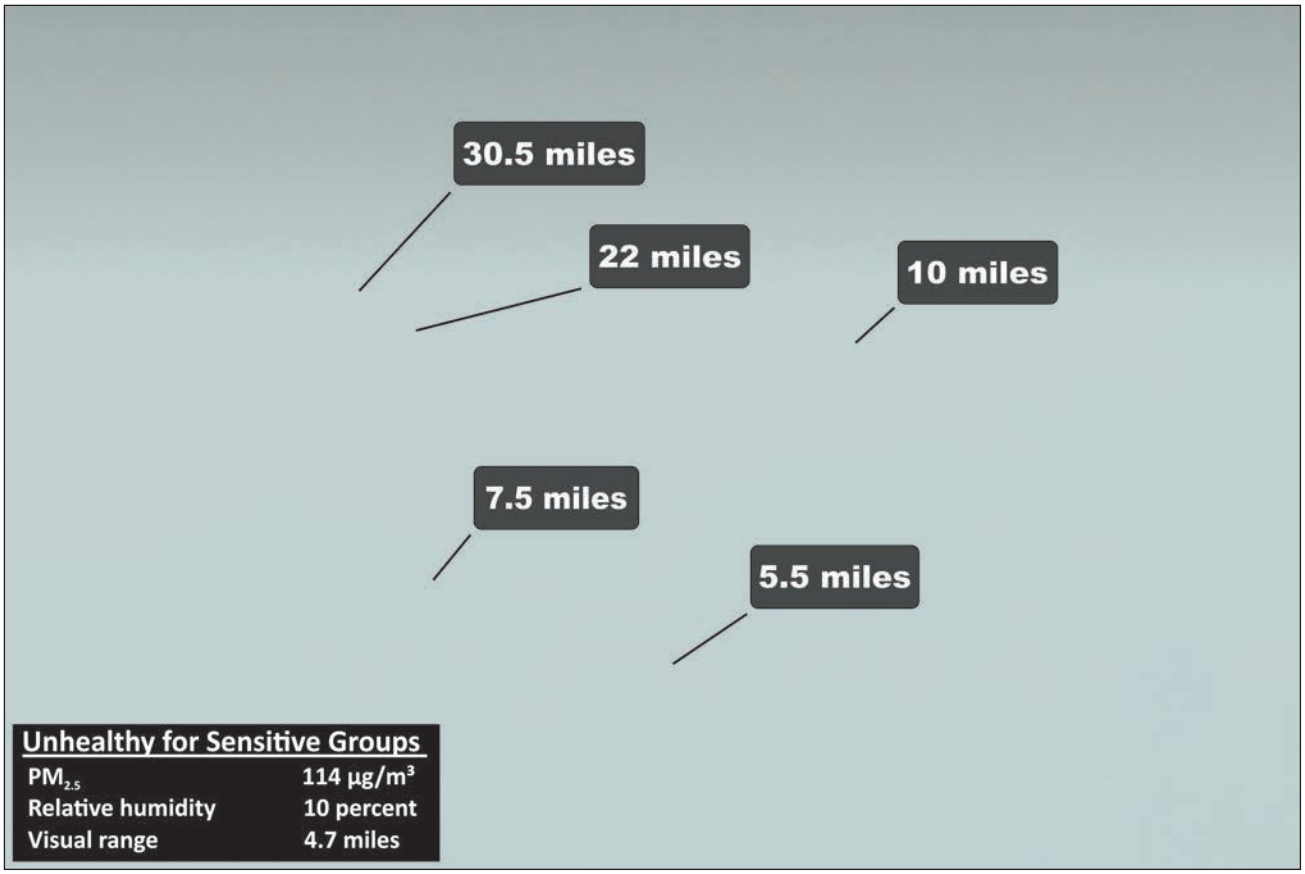
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<3 (Baseline)	10	109.4	176.0
19 (Good)	10	26.4	42.5
	20	26.0	41.8
	30	25.6	41.2
	40	25.1	40.4
	50	24.4	39.2
	60	23.5	37.9
114 (Unhealthy for Sensitive Groups)	10	4.7	7.6
	20	4.6	7.4
	30	4.5	7.3
	40	4.4	7.1
	50	4.3	7.0
	60	4.2	6.8
245 (Unhealthy)	10	2.2	3.5
	20 to 40	2.1	3.4
	50	2.0	3.2
	60	1.9	3.1

[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

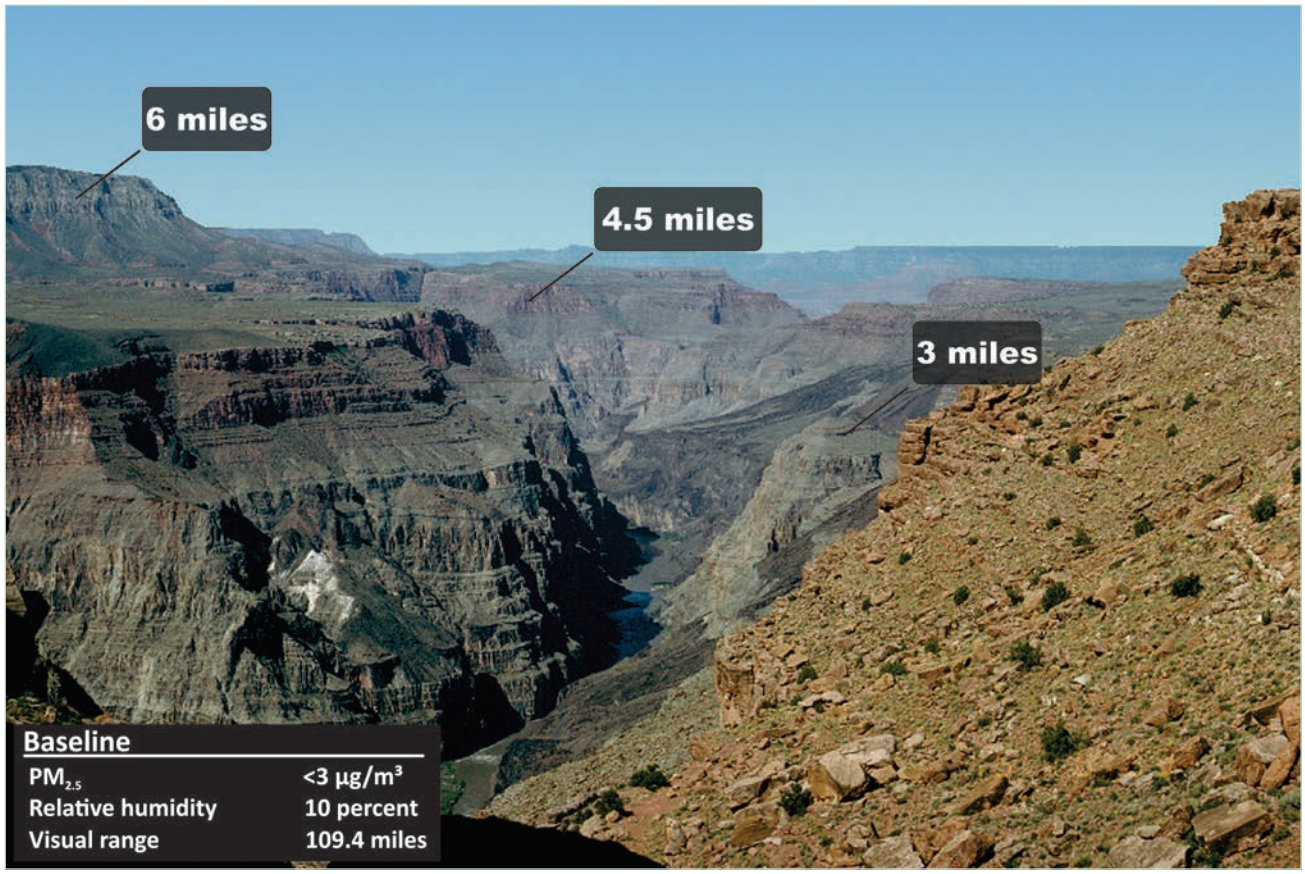
Grand Canyon National Park (Arizona)—Bluff View

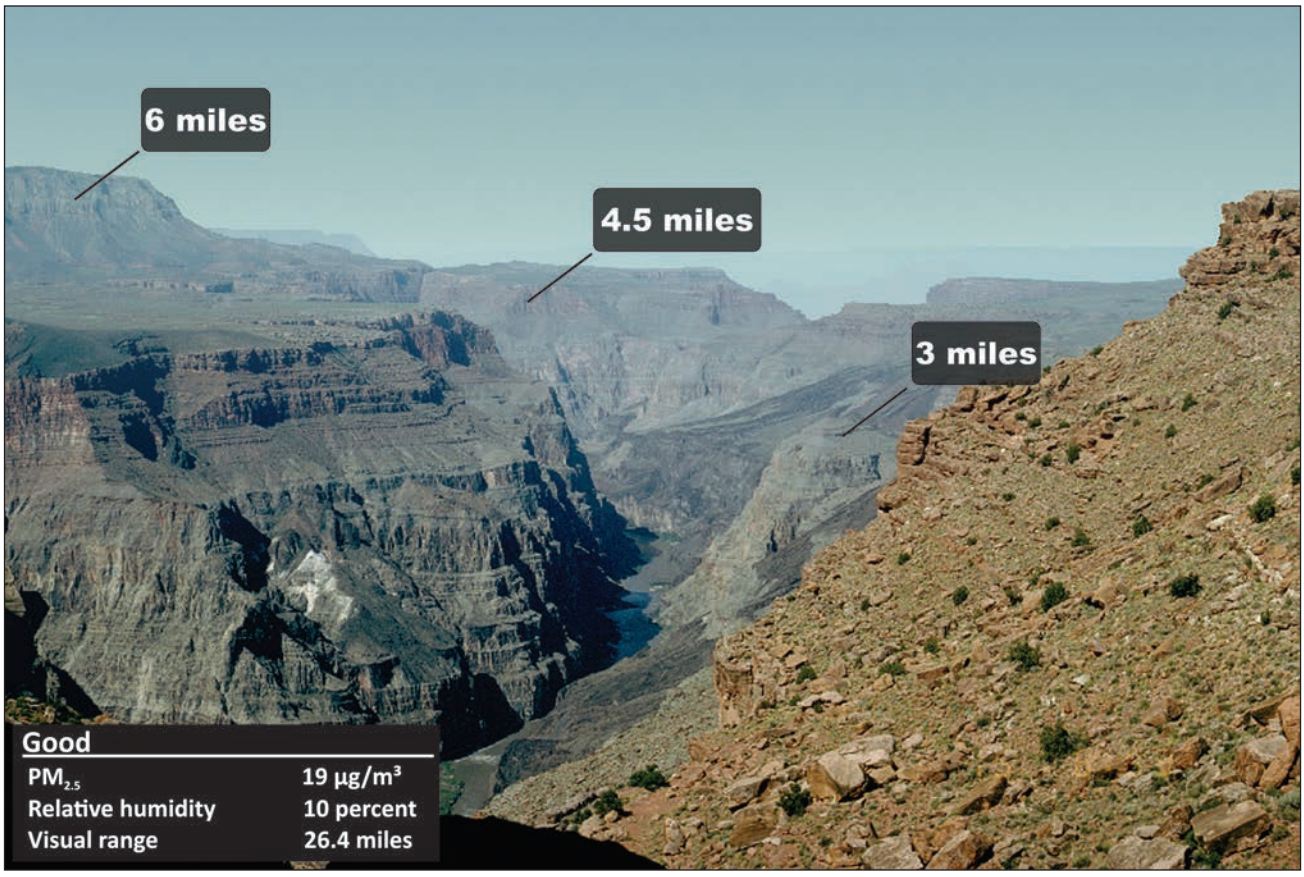


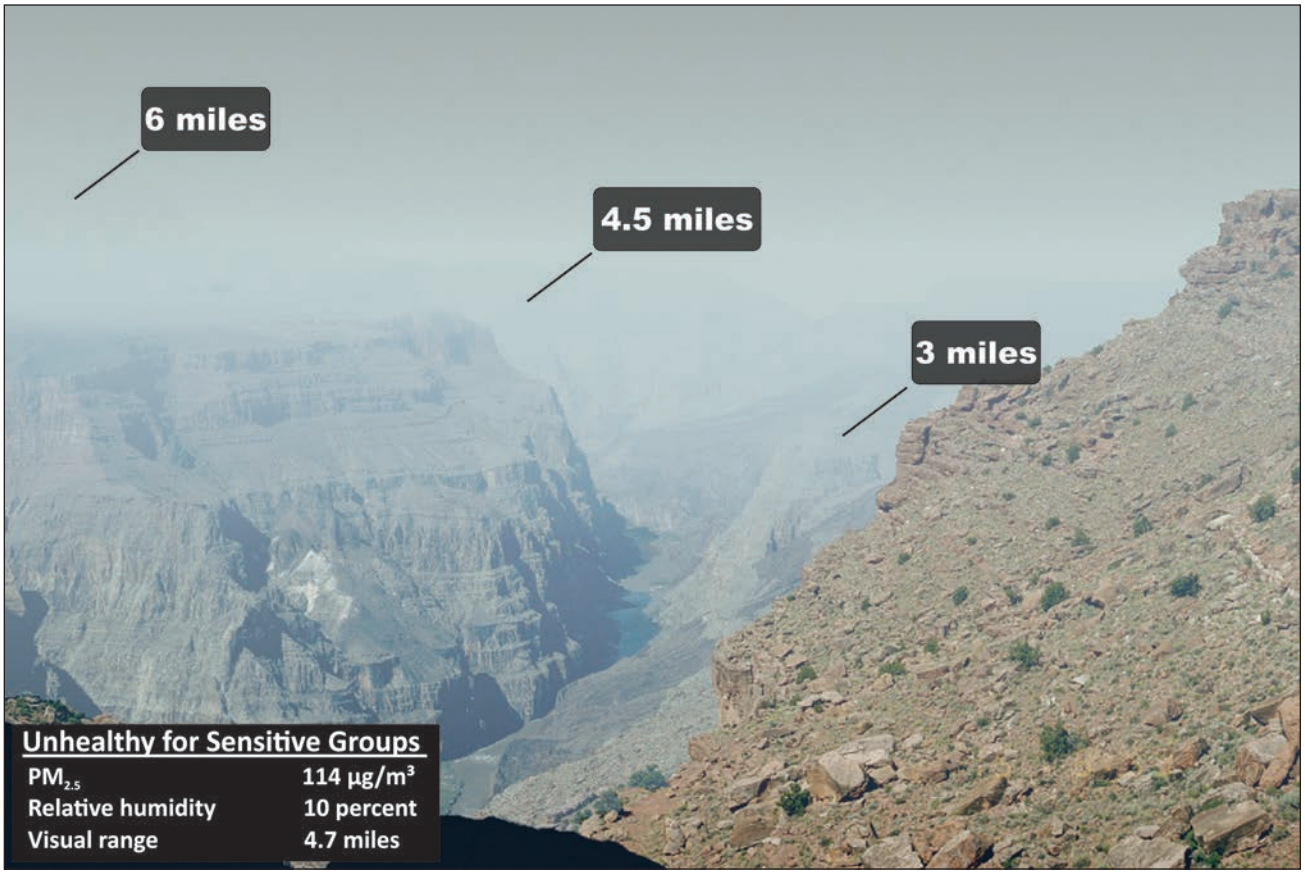


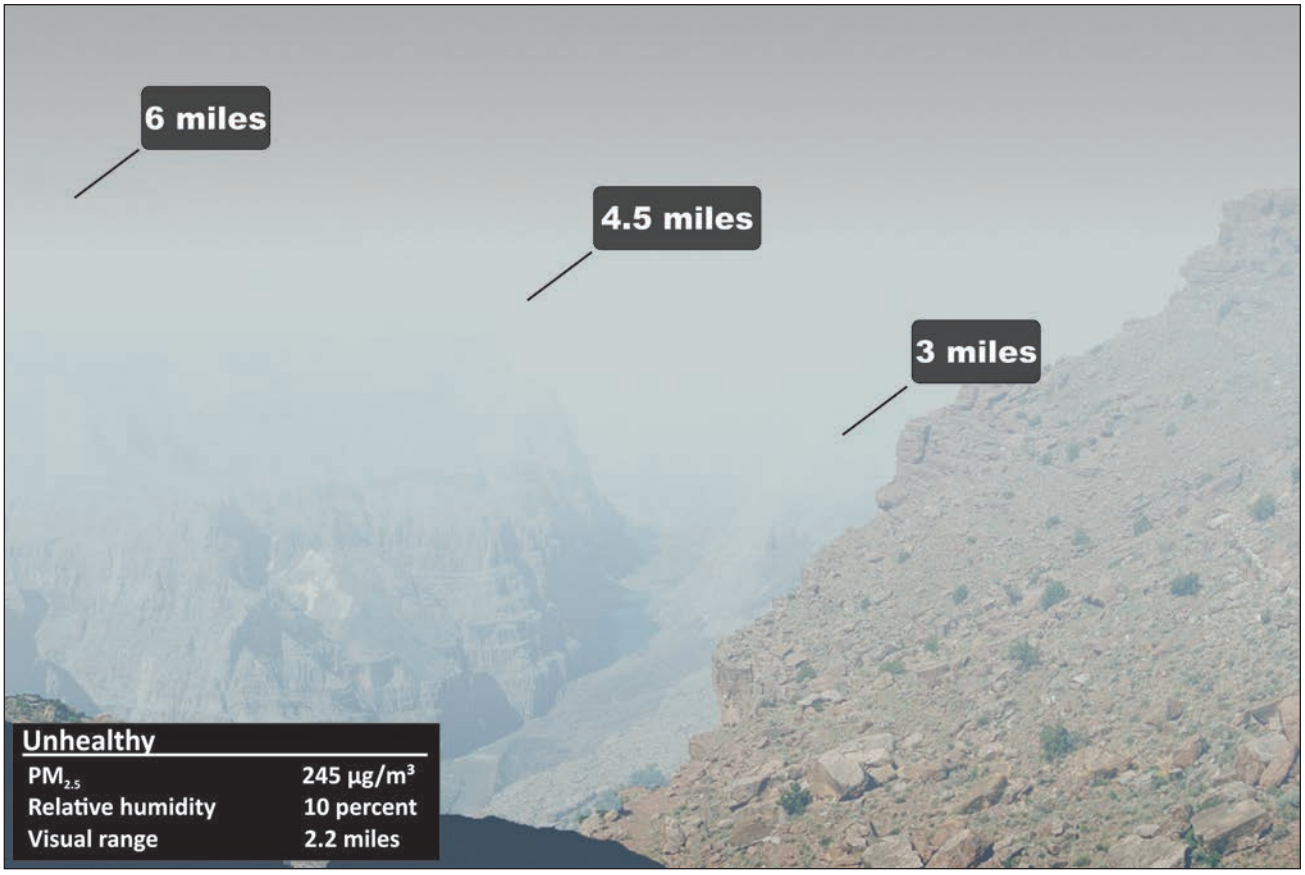

30.5 miles
22 miles
10 miles
7.5 miles
5.5 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m3
Relative humidity 10 percent
Visual range 4.7 miles

Grand Canyon National Park (Arizona)—Valley View






6 miles
4.5 miles
3 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 10 percent
Visual range 4.7 miles


6 miles
4.5 miles
3 miles
Unhealthy
PM2.5 245 µg/m³
Relative humidity 10 percent
Visual range 2.2 miles

Rocky Mountain Region (National Forest System—Region 4):

Canyonlands National Park (Utah)

Particulate data from 964 days (March 1988 to May 1999) at Canyonlands National Park were chosen to represent baseline and elevated regional air quality concentrations (table 8). Table 9 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<3, 19, 114, and 245 μg/m^3) and relative humidity for Canyonlands National Park. The simulated images show a baseline representing an area free from smoke-impaired visibility (<3 μg/m^3 fine and coarse particulates) and three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Canyonlands National Park (EPA 2014).

Table 8—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<3 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Canyonlands National Park, Utah

Particulate matter constituents	Particulate matter concentration			
	<3 (Baseline)	19	114	245
		μg/m³		
Ammonium sulfate	1.08	1.54	1.54	1.54
Ammonium nitrate	0.23	0.37	0.37	0.37
Organic carbon	0.82	14.77	103.96	226.95
Black carbon	0.16	0.96	6.77	14.78
Fine soil	0.69	1.36	1.36	1.36
Coarse mass	5.60	8.43	11.40	24.50

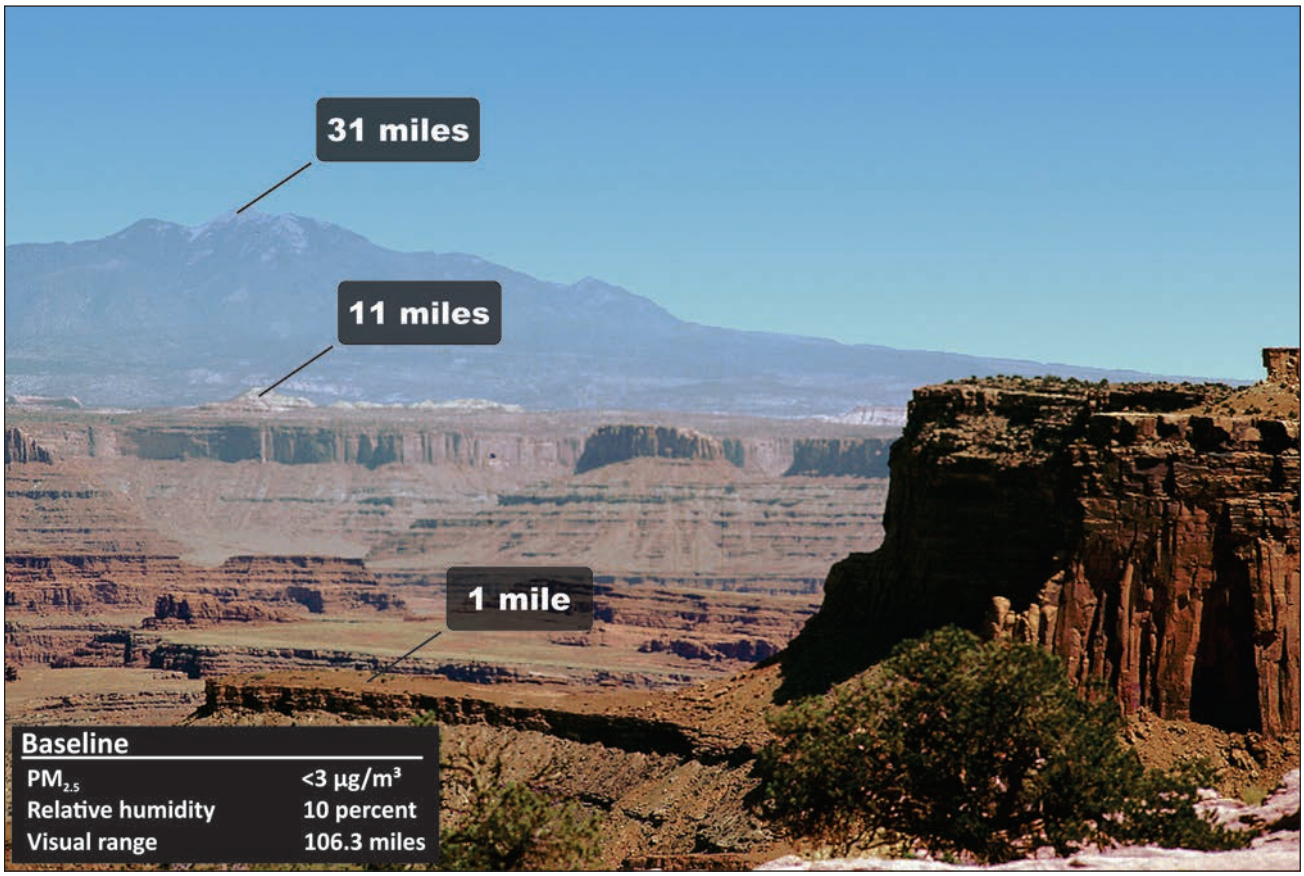
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

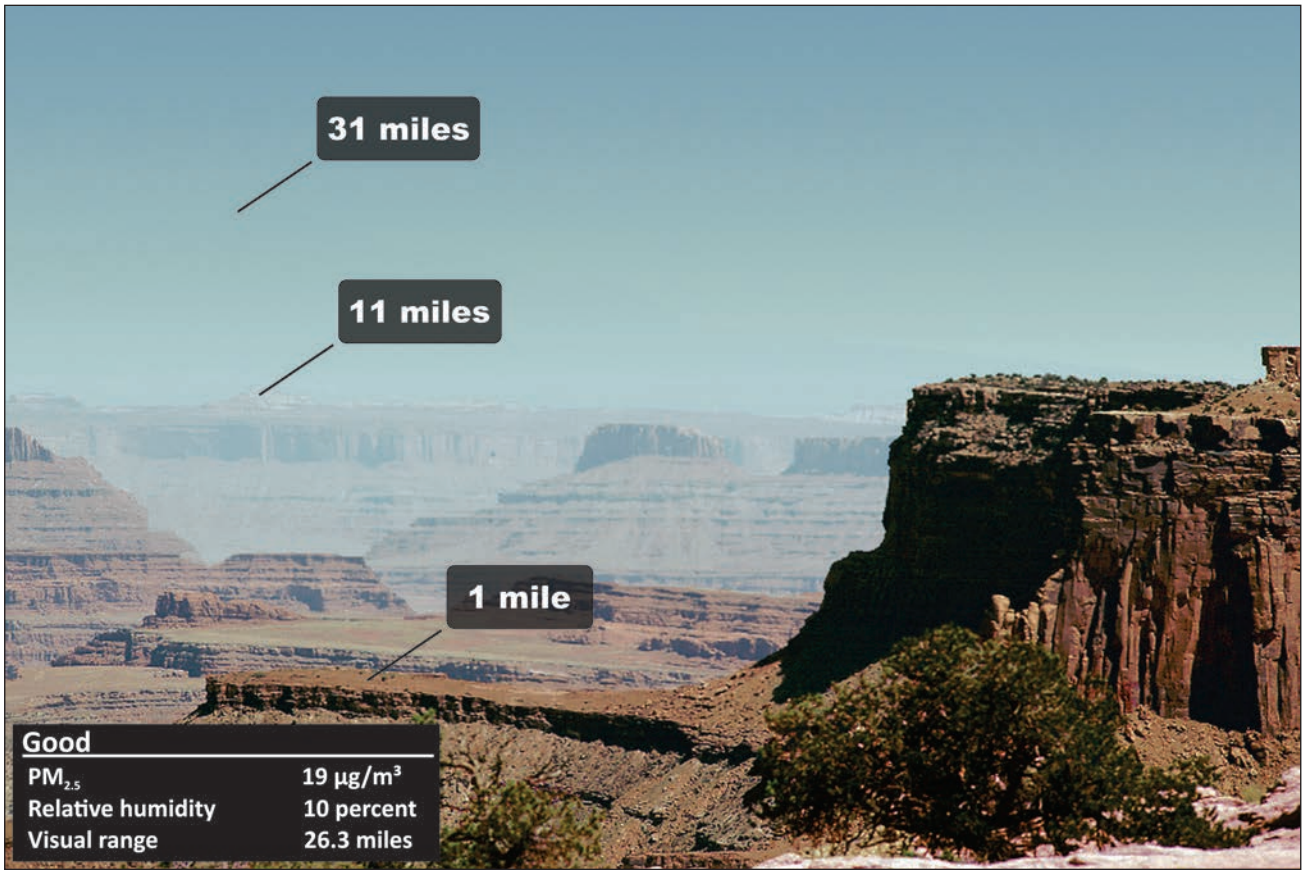
Table 9—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Canyonlands National Park, Utah

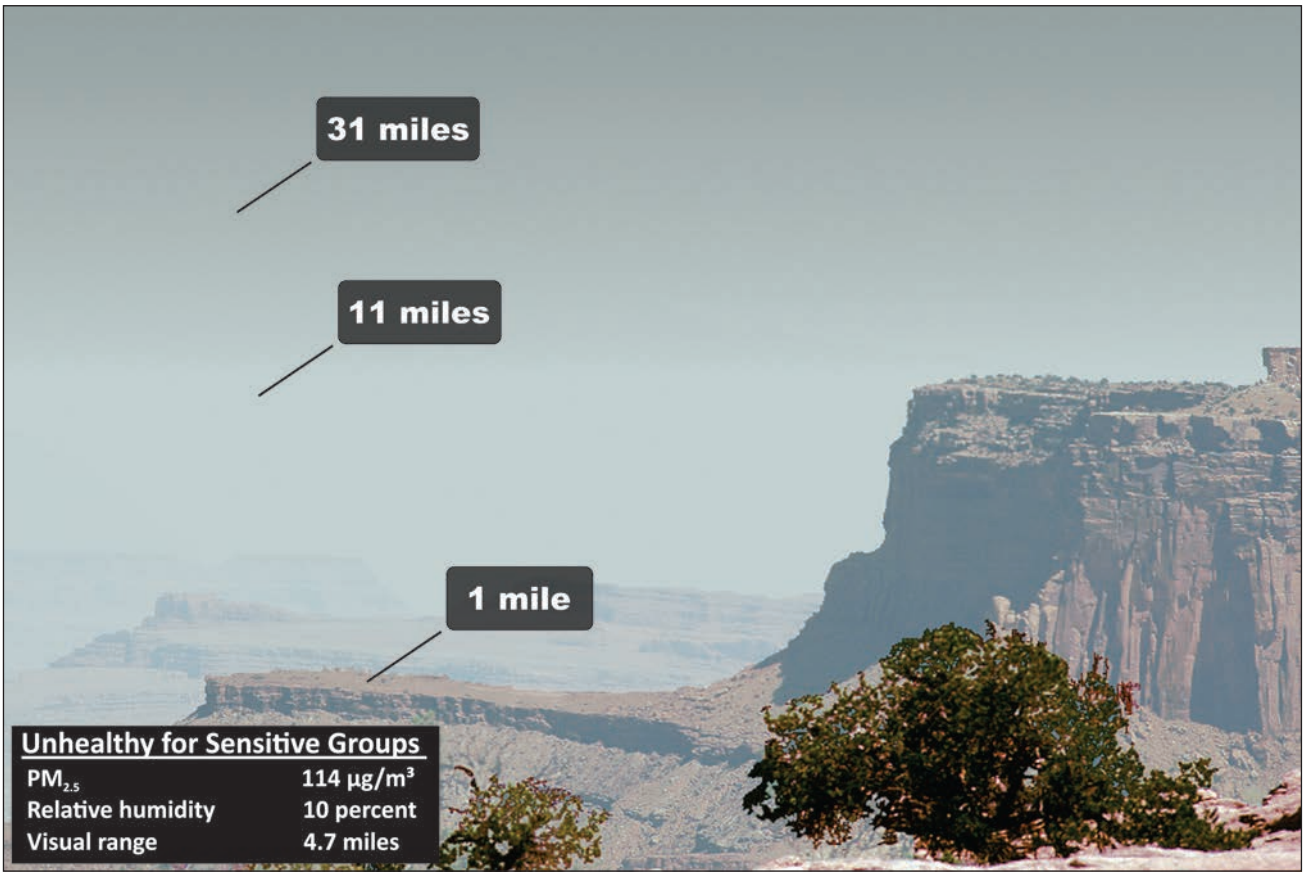
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<3 (Baseline)	10	106.3	171.0
19 (Good)	10	26.3	42.4
	20	26.0	41.8
	30	25.5	41.1
	40	25.0	40.3
114 (Unhealthy for Sensitive Groups)	10	4.7	7.6
	20	4.6	7.4
	30	4.5	7.3
	40	4.4	7.1
245 (Unhealthy)	10	2.2	3.5
	20 to 40	2.1	3.4

[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Canyonlands National Park (Utah)






31 miles
11 miles
1 mile
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 10 percent
Visual range 4.7 miles


31 miles
11 miles
1 mile
Unhealthy
PM2.5 245 µg/m³
Relative humidity 10 percent
Visual range 2.2 miles

Rocky Mountain Region (National Forest System—Region 4):

Great Basin National Park (Nevada)

Particulate data from 681 days of sampling (May 1992 to May 1999) at Great Basin National Park were chosen to represent baseline and elevated regional air quality concentrations (table 10). Table 11 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<3, 19, 114, and 245 μg/m^3) and relative humidity for Great Basin National Park. The simulated images show a baseline representing an area free from smoke-impaired visibility (<3 μg/m^3 fine and coarse particulates) and two levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Great Basin National Park (EPA 2014).

Table 10—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<3 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Great Basin National Park, Nevada

Particulate matter constituents	Particulate matter concentration			
	<3 (Baseline)	19	114	245
		μ/gm^3		
Ammonium sulfate	0.68	1.13	1.13	1.13
Ammonium nitrate	0.16	0.31	0.31	0.31
Organic carbon	0.98	15.18	104.37	227.37
Black carbon	0.19	0.99	6.80	14.81
Fine soil	0.60	1.39	1.39	1.39
Coarse mass	3.73	5.50	11.40	24.50

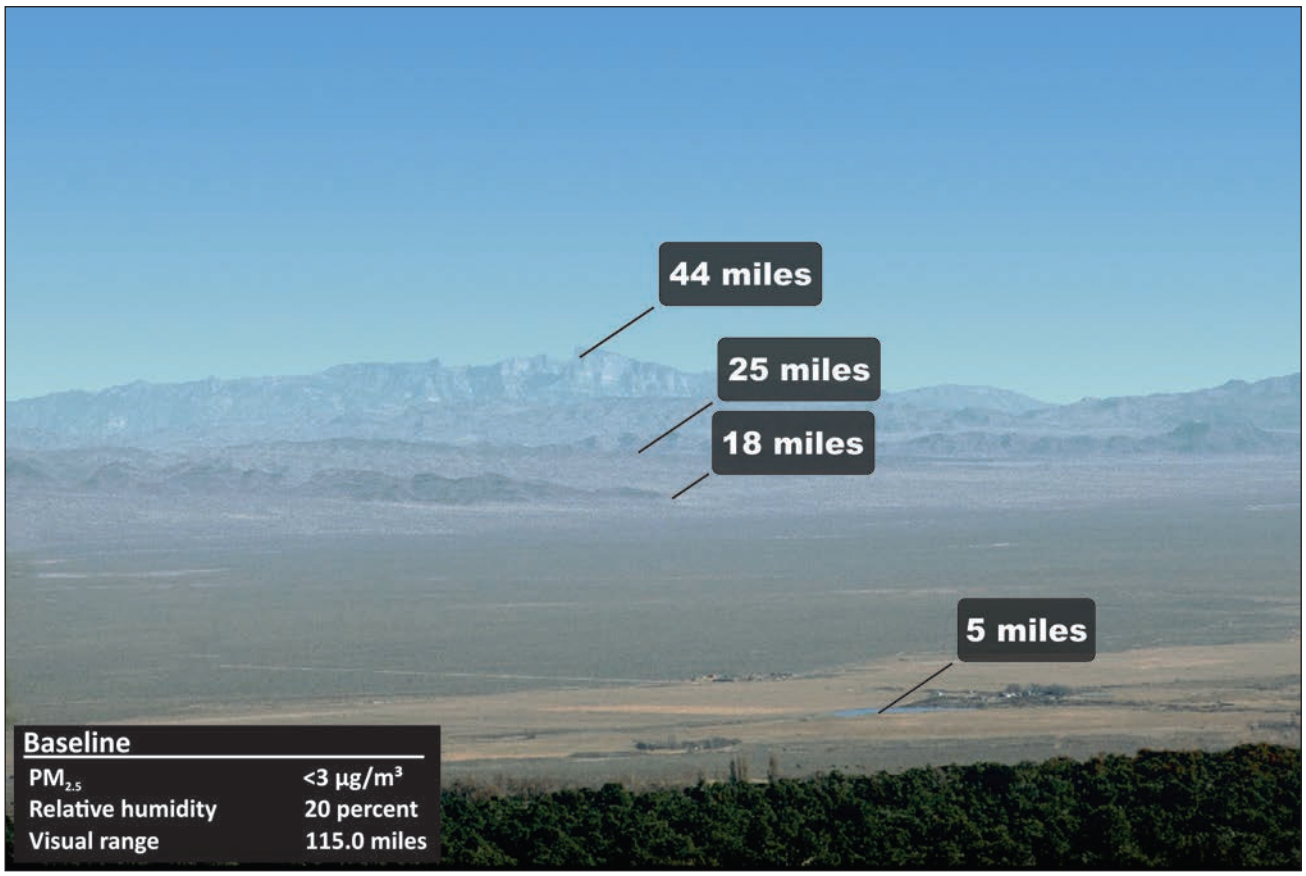
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

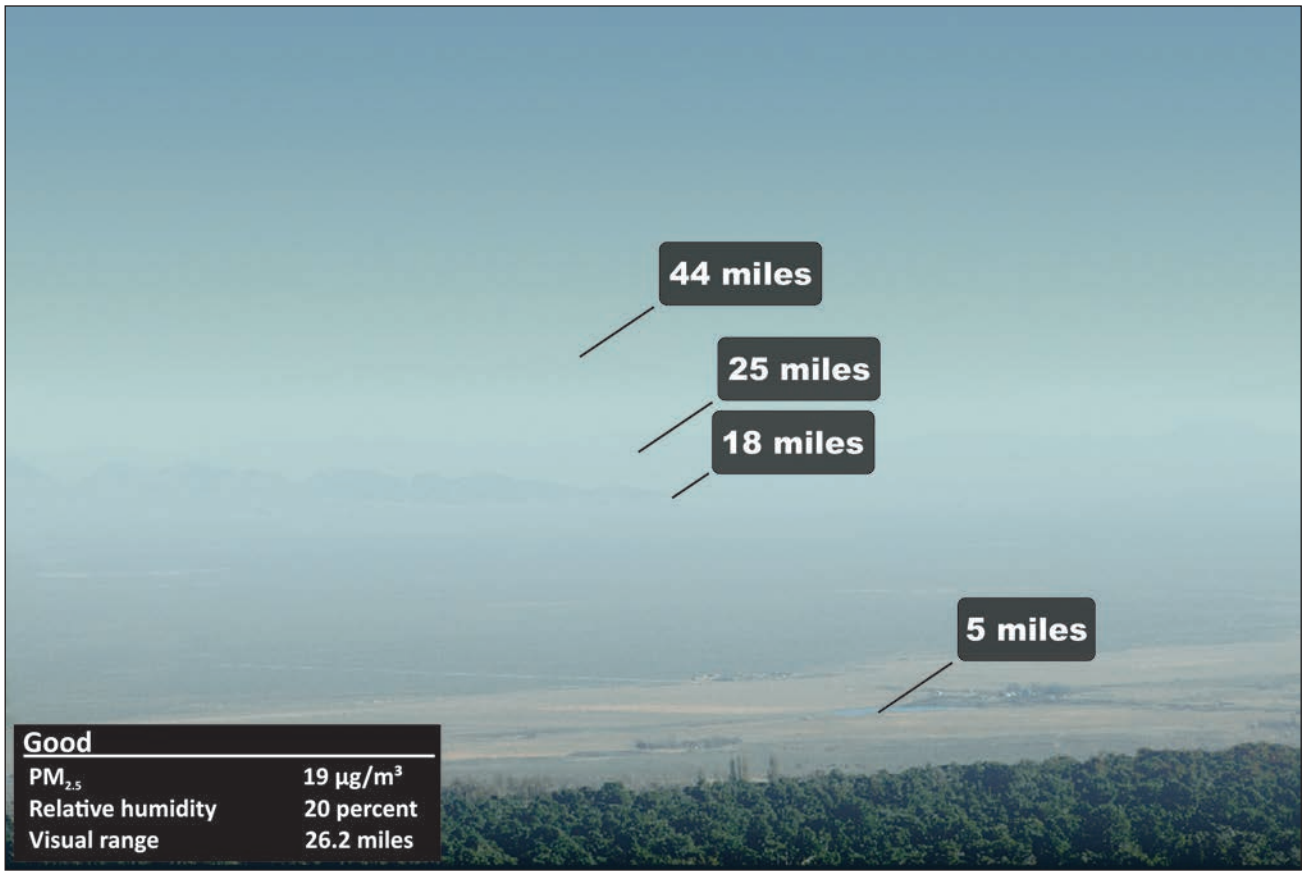
Table 11—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Great Basin National Park, Nevada

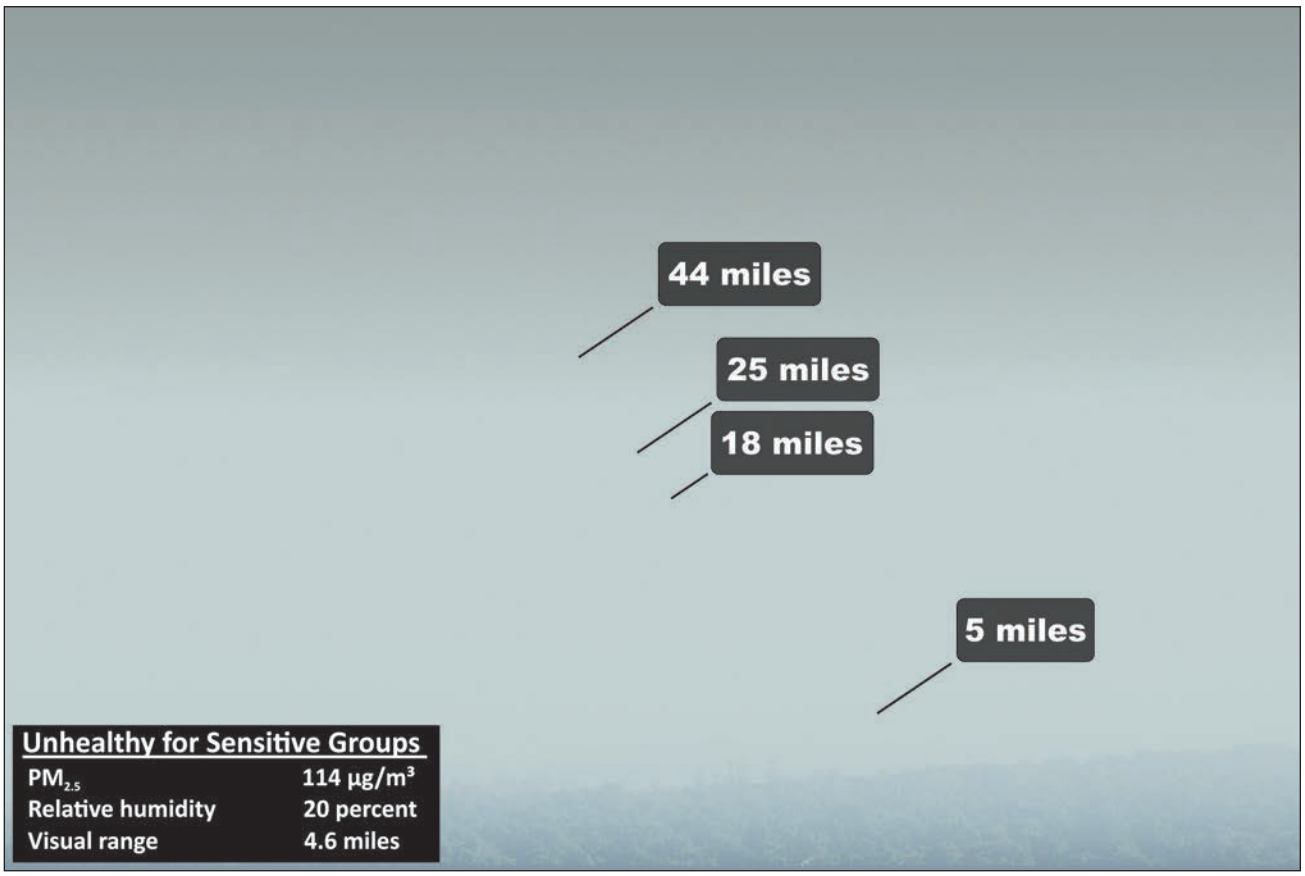
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<3 (Baseline)	20	115.0	185.0
19 (Good)	20	26.2	42.2
	30	25.8	41.6
	40	25.4	40.8
	50	24.7	39.7
114 (Unhealthy for Sensitive Groups)	20	4.6	7.4
	30	4.5	7.3
	40	4.4	7.1
	50	4.3	7.0
245	20 to 40	2.1	3.4
	50	2.0	3.3

[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Great Basin National Park (Nevada)






44 miles
25 miles
18 miles
5 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m3
Relative humidity 20 percent
Visual range 4.6 miles

Pacific Southwest Region (National Forest System—Region 5):

Yosemite National Park (California)

Particulate data from 951 days (March 1988 to May 1999) at Yosemite National Park were chosen to represent baseline and elevated regional air quality concentrations (table 12). Table 13 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<5, 19, 114, and 245 μg/m^3) and relative humidity for Yosemite National Park. The simulated images show a baseline representing an area free from smoke-impaired visibility (<5 μg/m^3 fine and coarse particulates) and three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Yosemite National Park (EPA 2014).

Table 12—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<5 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Yosemite National Park, California

Particulate matter constituents	Particulate matter concentration			
	<5 (Baseline)	19	114	245
		μg/m³		
Ammonium sulfate	0.99	1.90	1.90	1.90
Ammonium nitrate	0.47	0.94	0.94	0.94
Organic carbon	1.94	14.20	103.39	226.38
Black carbon	0.27	0.92	6.73	14.74
Fine soil	0.56	1.04	1.04	1.04
Coarse mass	4.78	7.64	11.40	24.50

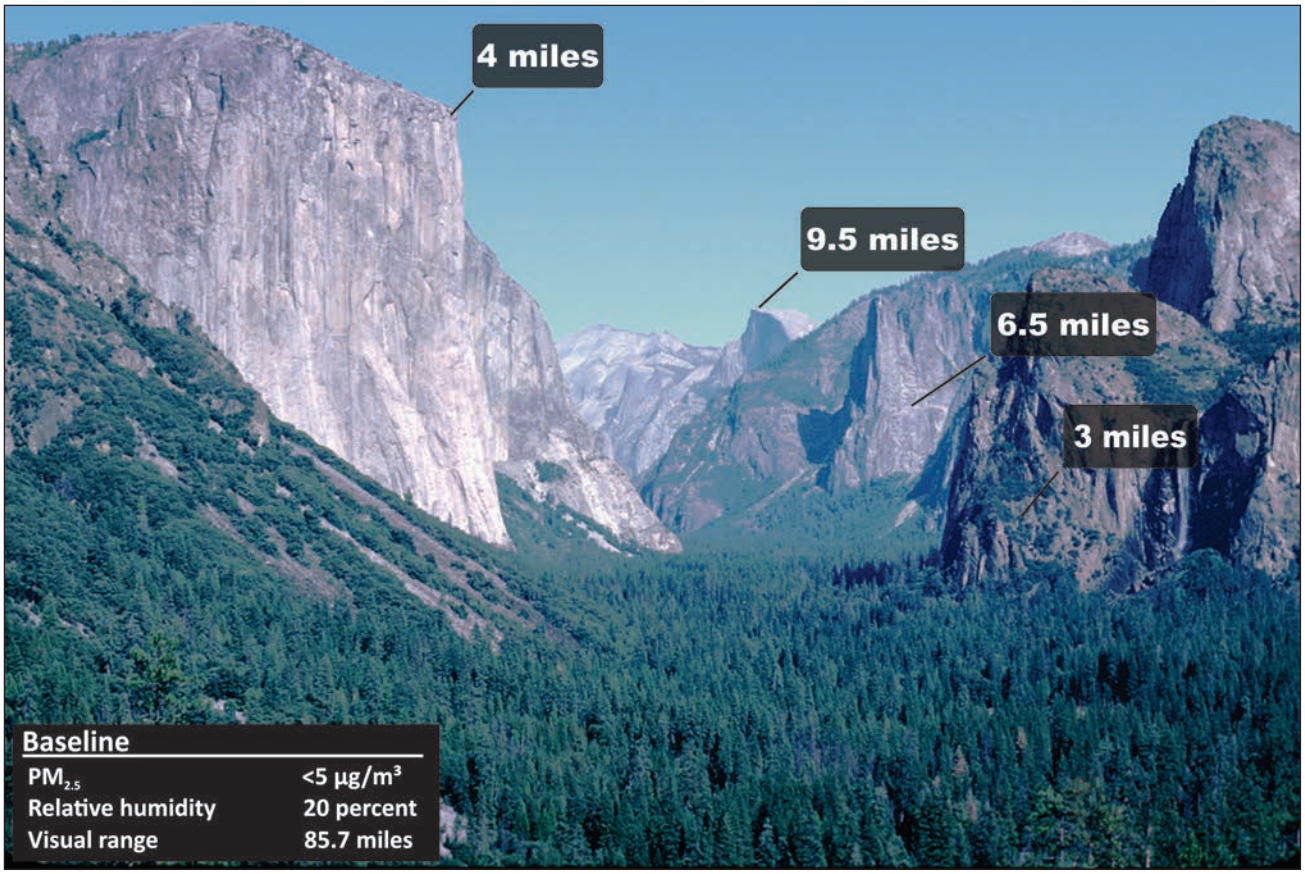
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

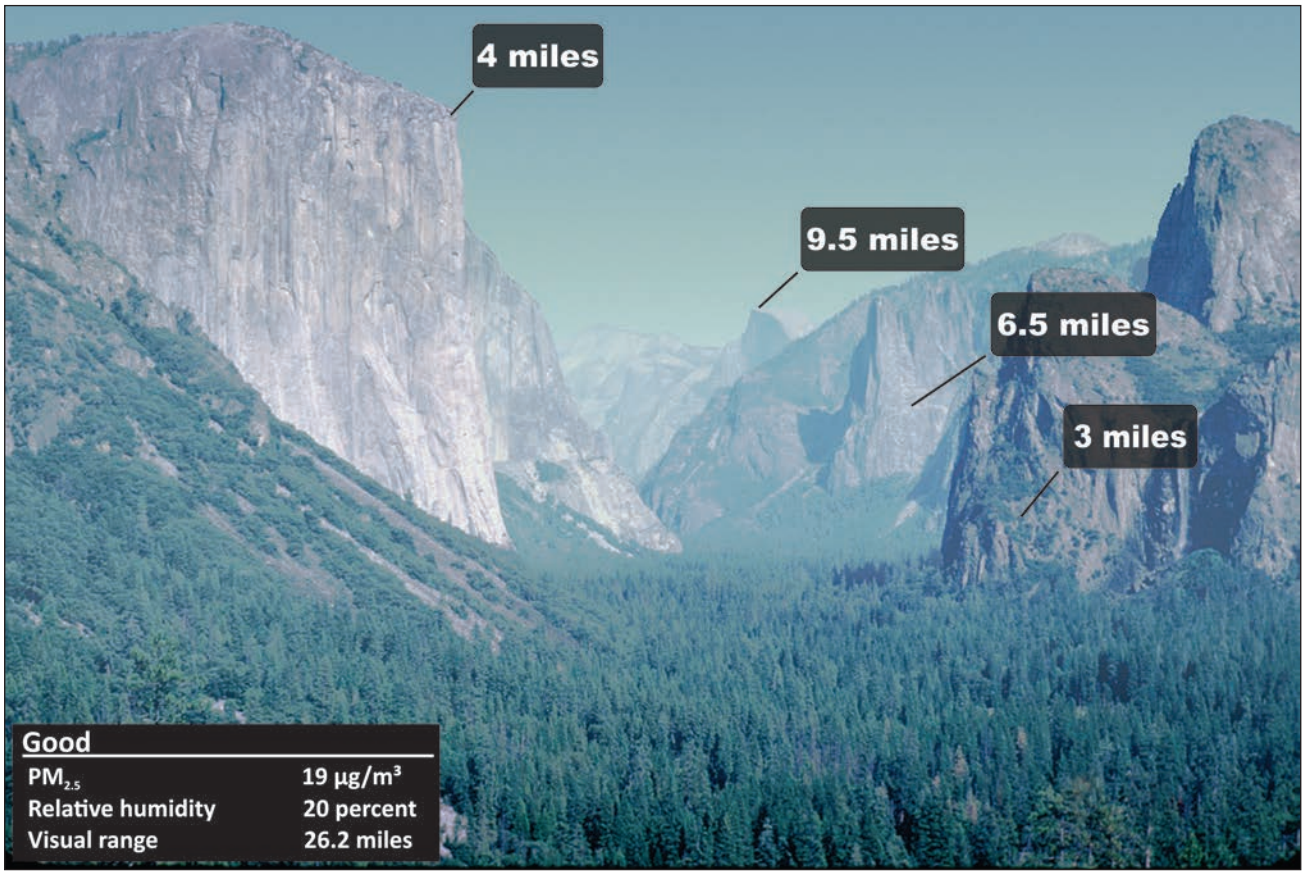
Table 13—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Yosemite National Park, California

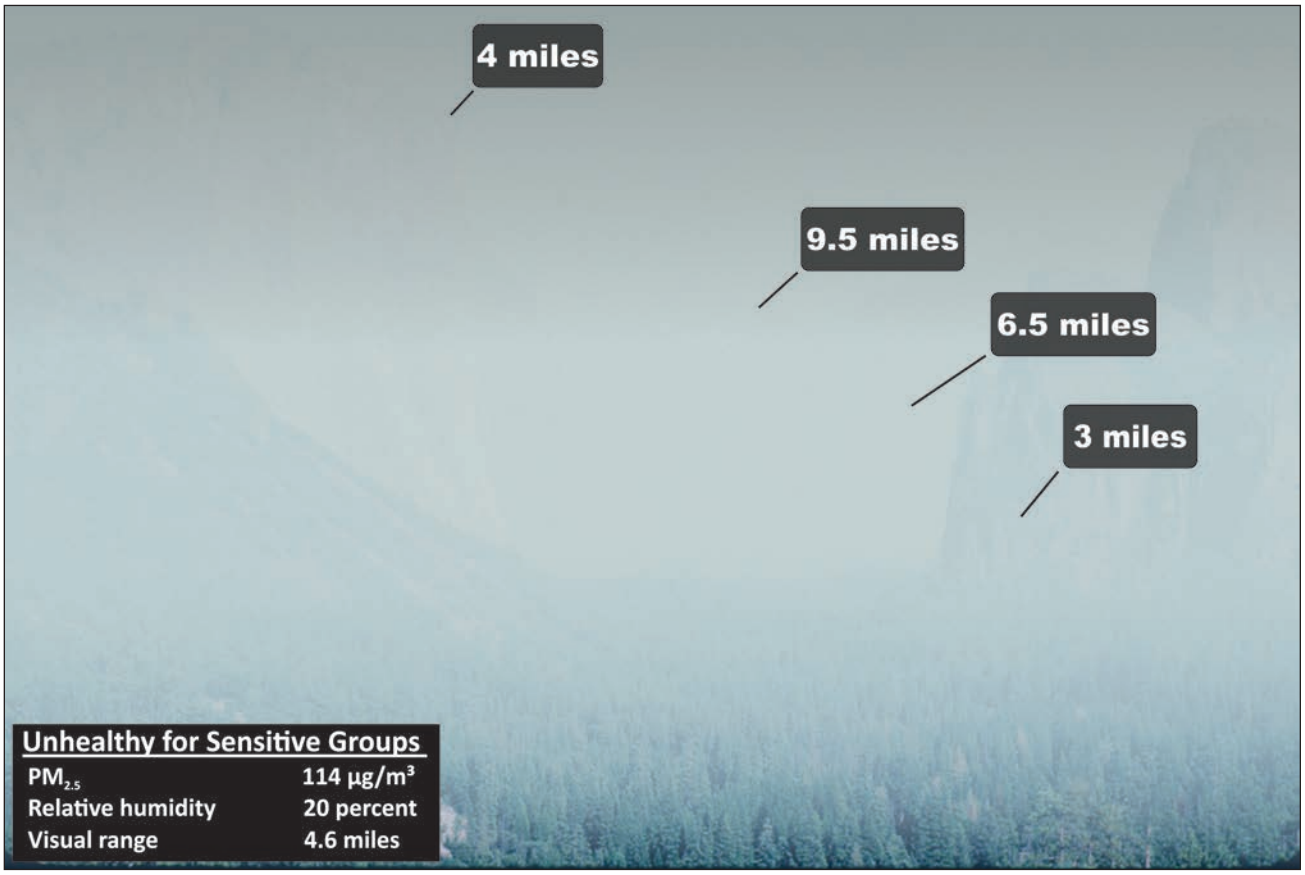
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<5 (Baseline)	20	85.7	138.0
19 (Good)	20	26.2	42.1
	30	25.8	41.5
	40	25.2	40.6
	50	24.4	39.2
114 (Unhealthy for Sensitive Groups)	20	4.6	7.4
	30	4.5	7.3
	40	4.4	7.1
	50	4.3	7.0
245 (Unhealthy)	20	2.1	3.4
	50	2.0	3.2

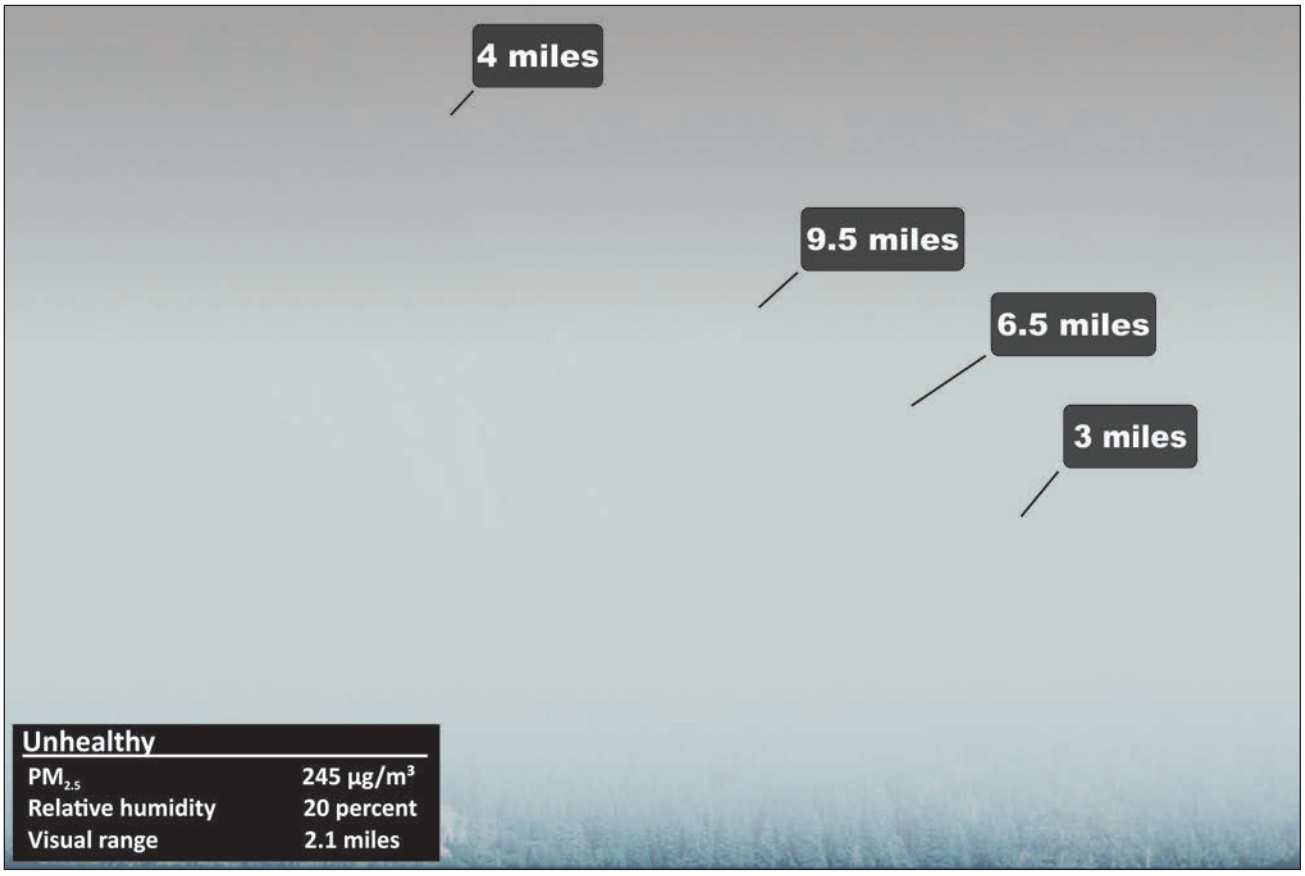
[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Yosemite National Park (California)






4 miles
9.5 miles
6.5 miles
3 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 20 percent
Visual range 4.6 miles


4 miles
9.5 miles
6.5 miles
3 miles
Unhealthy
PM2.5 245 µg/m³
Relative humidity 20 percent
Visual range 2.1 miles

Pacific Northwest Region (National Forest System—Region 6):

Columbia River Gorge National Scenic Area (Oregon)

Particulate data from 551 days of sampling (July 1993 to May 1999) in the Columbia River Gorge National Scenic Area were chosen to represent baseline and elevated regional air quality concentrations (table 14). Table 15 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<6, 19, 114, and 245 μg/m^3) and relative humidity for the Columbia River Gorge National Scenic Area. The simulated images show a baseline representing an area free from smoke-impaired visibility (<6 μg/m^3 fine and coarse particulates) and three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Portland, Oregon (NOAA 2014).

Table 14—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<6 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in the Columbia River Gorge National Scenic Area, Oregon

Particulate matter constituents	Particulate matter concentration			
	<6 (Baseline)	19	114	245
		μg/m^3		
Ammonium sulfate	1.48	2.56	2.56	2.56
Ammonium nitrate	0.77	1.78	1.78	1.78
Organic carbon	2.32	12.56	101.75	224.75
Black carbon	0.47	0.82	6.63	14.63
Fine soil	0.66	1.28	1.28	1.28
Coarse mass	7.90	11.88	11.88	24.50

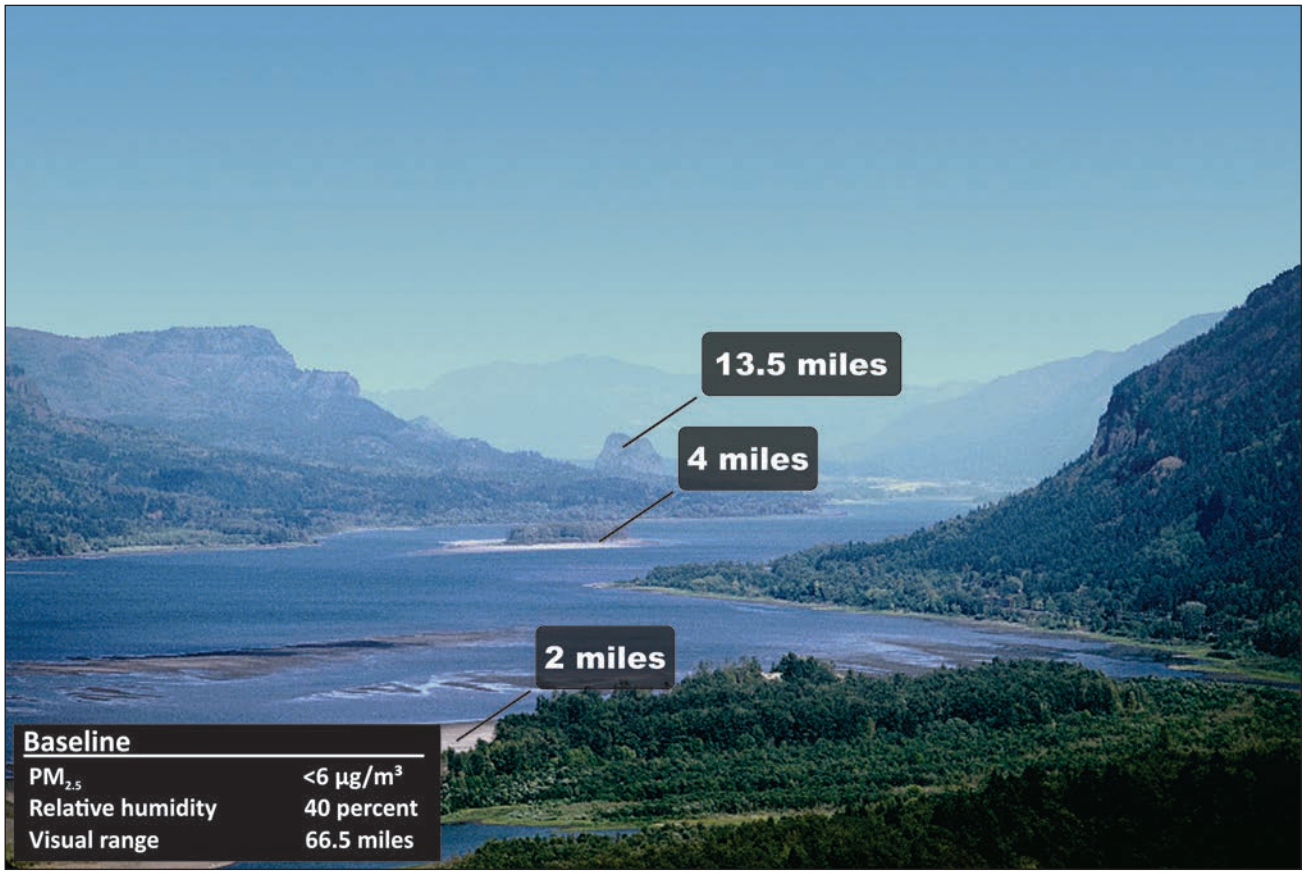
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

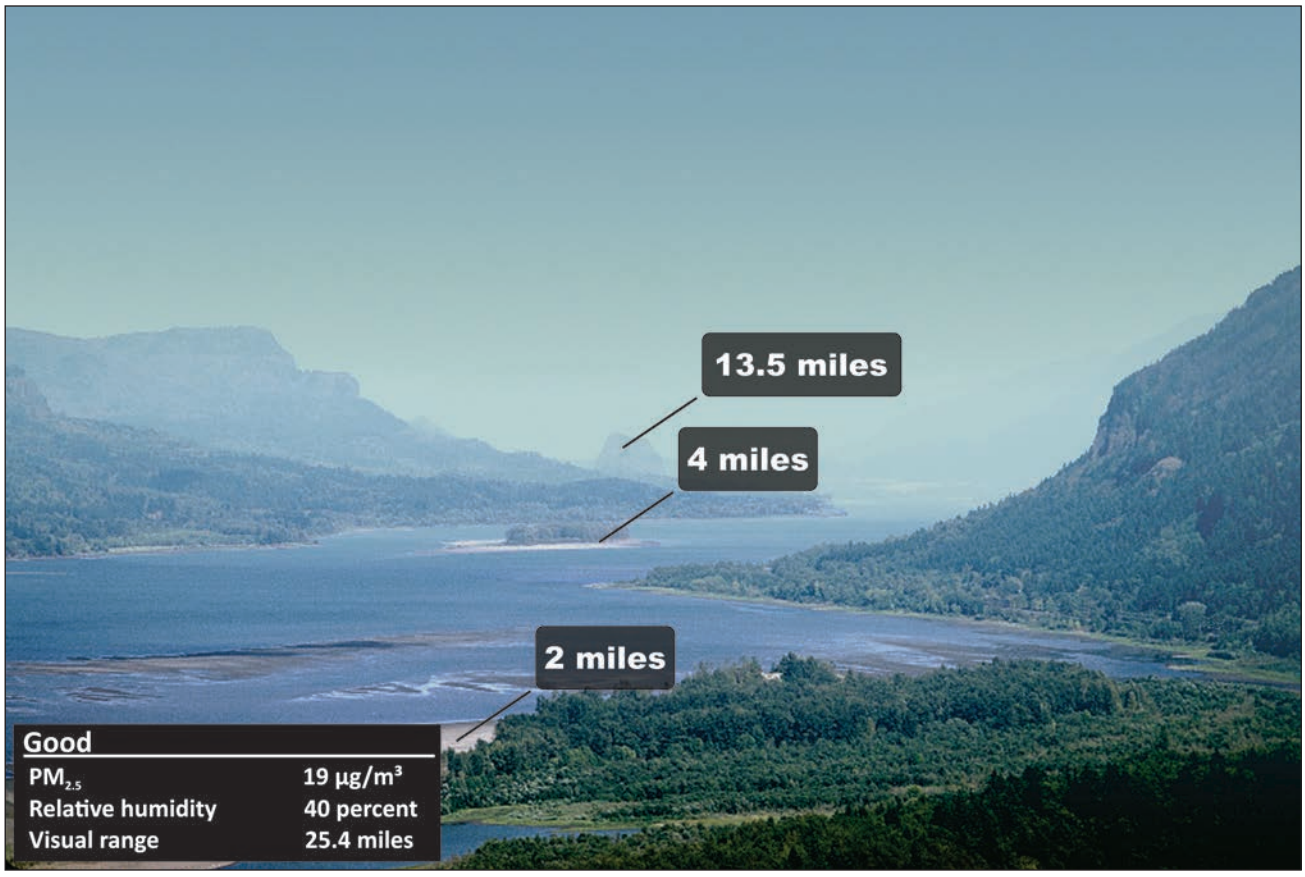
Table 15—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in the Columbia River Gorge National Scenic Area, Oregon

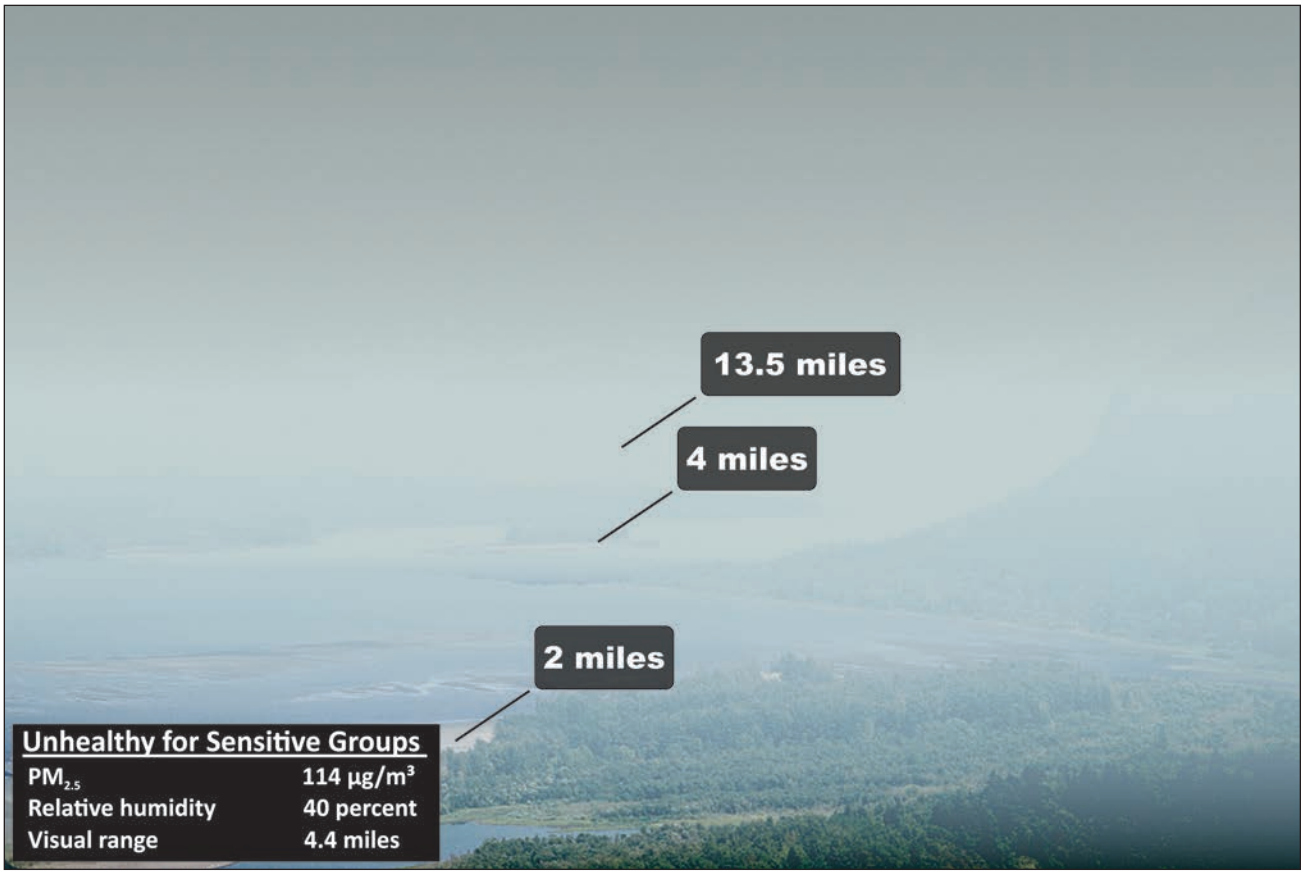
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<6 (Baseline)	40	66.5	107.0
19 (Good)	40	25.4	40.8
	50	24.2	39.0
	60	22.9	36.9
	70	21.5	34.6
	80	19.9	32.0
114 (Unhealthy for Sensitive Groups)	40	4.4	7.2
	50	4.3	7.0
	60	4.2	6.8
	70	4.1	6.6
	80	4.0	6.4
245 (Unhealthy)	40	2.1	3.3
	50 to 60	2.0	3.2
	70 to 80	1.9	3.1

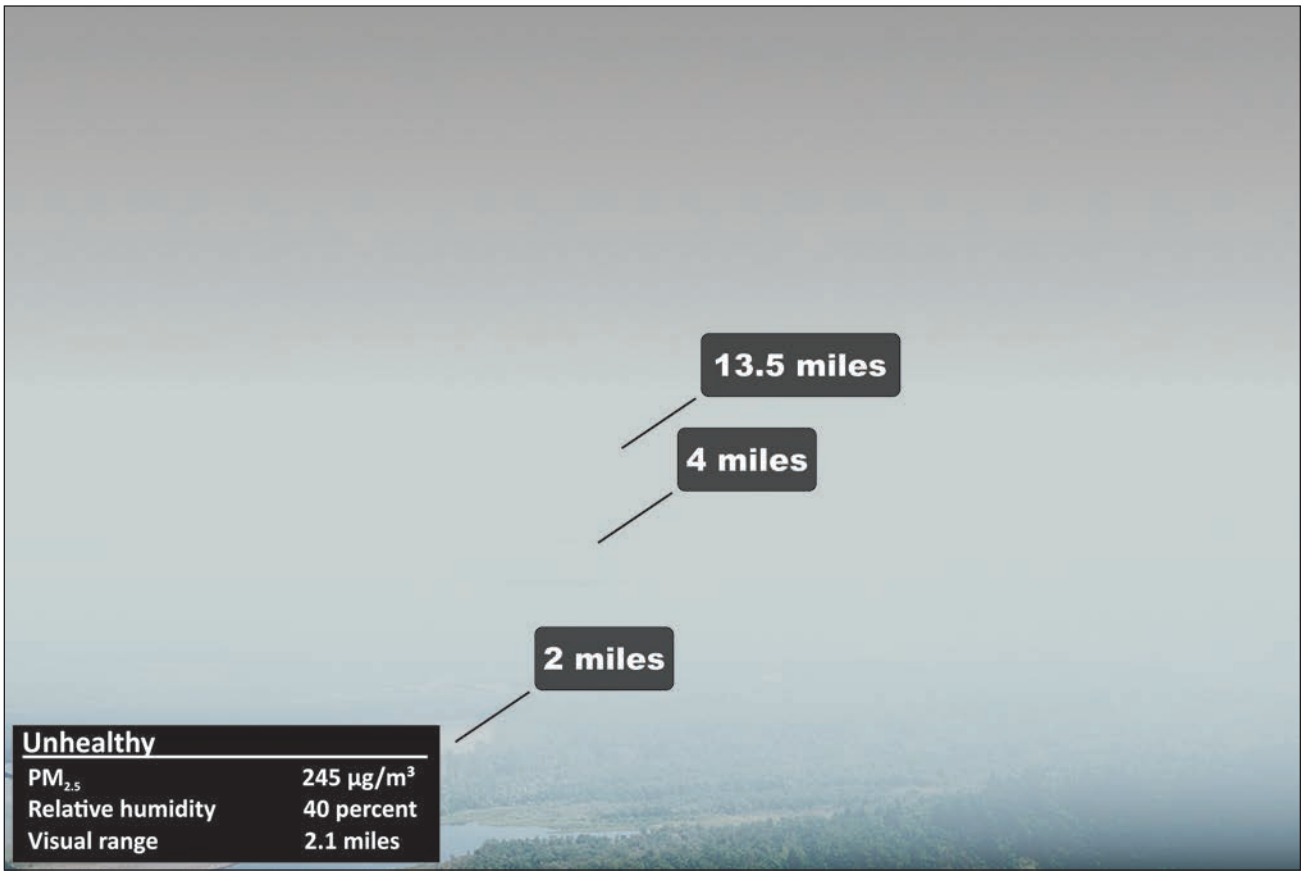
[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Columbia River Gorge National Scenic Area (Oregon)






13.5 miles
4 miles
2 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 40 percent
Visual range 4.4 miles


13.5 miles
4 miles
2 miles
Unhealthy
PM2.5 245 µg/m³
Relative humidity 40 percent
Visual range 2.1 miles

Pacific Northwest Region (National Forest System—Region 6):

Snoqualmie Pass (Washington)

Particulate data from 353 days of sampling (December 1993 to May 1999) at Snoqualmie Pass were chosen to represent baseline and elevated regional air quality concentrations (table 16). Table 17 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<4, 19, 114, and 245 μg/m^3) and relative humidity for Snoqualmie Pass. The simulated images show a baseline representing an area free from smoke-impaired visibility (<4 μg/m^3 fine and coarse particulates) and three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Seattle-Tacoma International Airport, Washington (NOAA 2014).

Table 16—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<4 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels at Snoqualmie Pass, Washington

Particulate matter constituents	Particulate matter concentration			
	<4 (Baseline)	19	114	245
	μg/m^3			
Ammonium sulfate	0.98	1.84	1.84	1.84
Ammonium nitrate	0.35	0.59	0.59	0.59
Organic carbon	1.28	14.80	103.99	226.98
Black carbon	0.31	0.96	6.77	14.78
Fine soil	0.29	0.81	0.81	0.81
Coarse mass	2.94	3.82	11.40	24.50

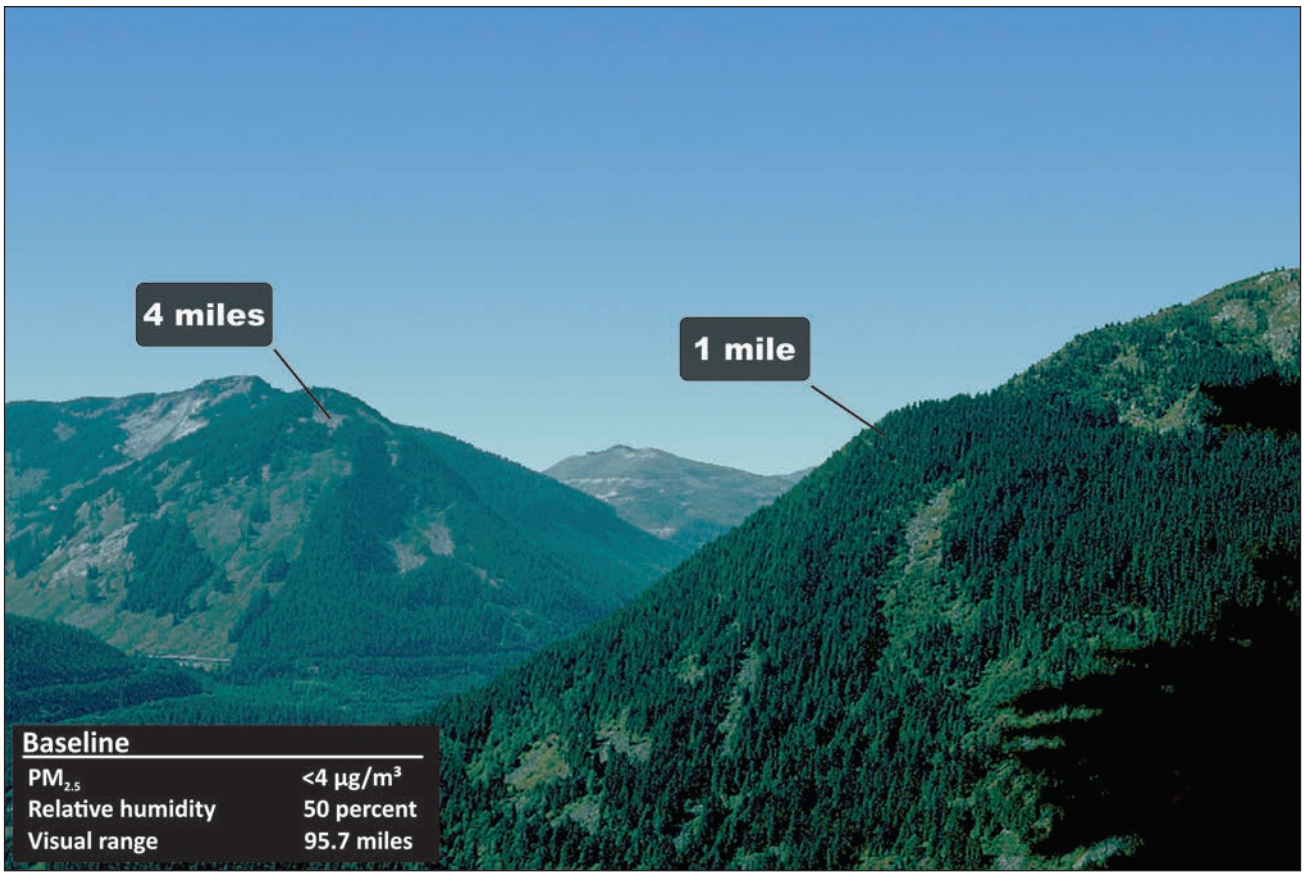
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

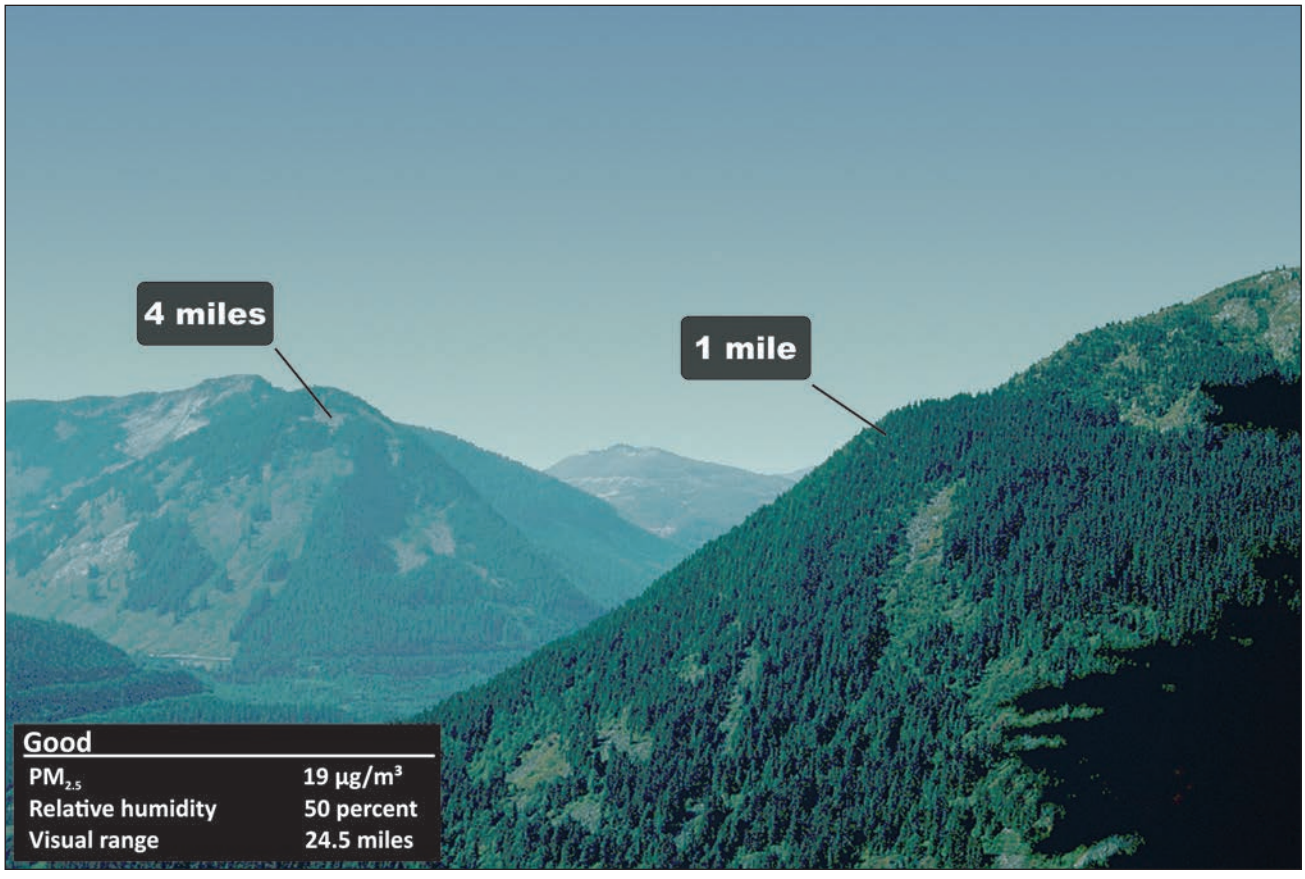
Table 17—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity at Snoqualmie Pass, Washington

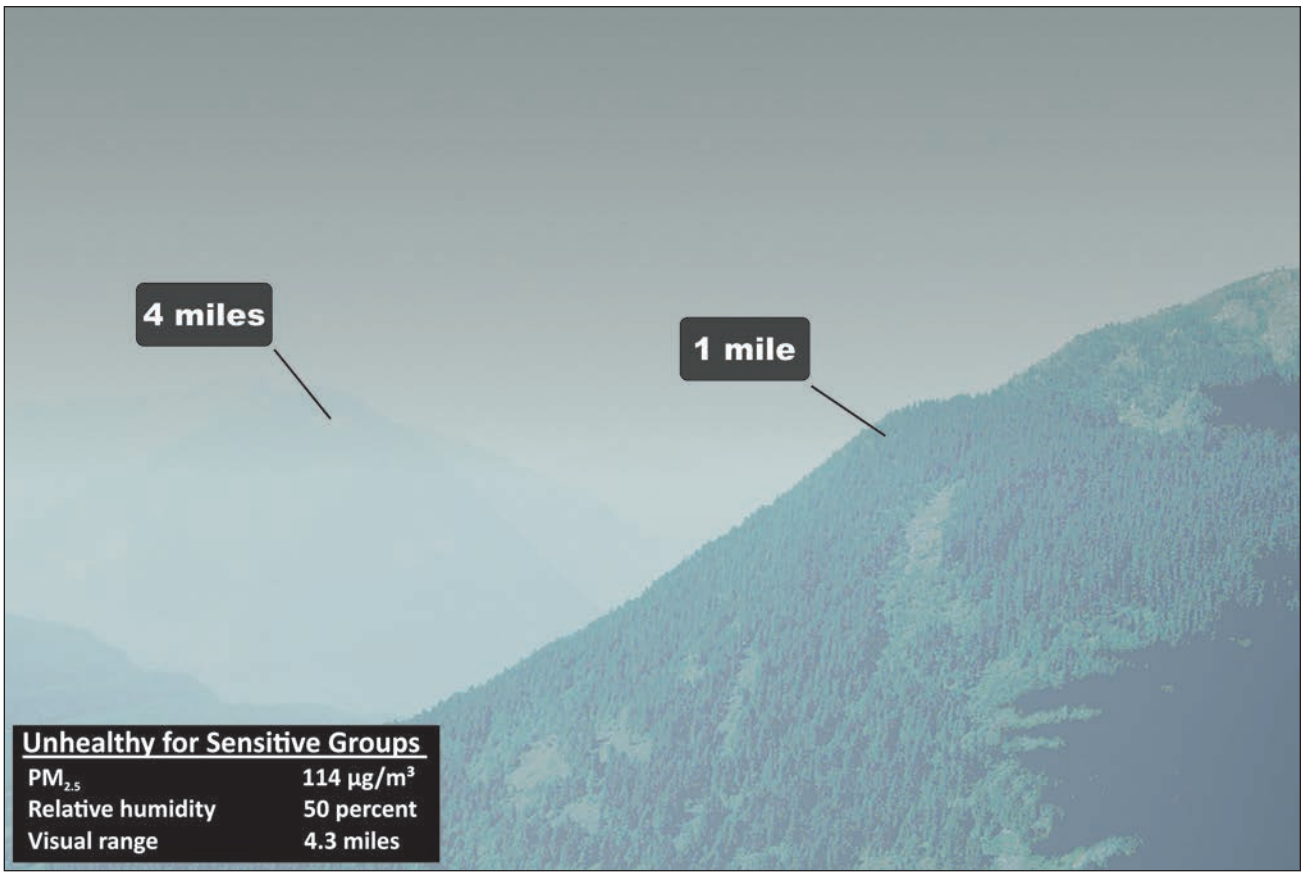
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<4 (Baseline)	50	95.7	154.0
19 (Good)	50	24.5	39.5
	60	23.6	38.0
	70	22.6	36.3
	80	21.4	34.4
	90	19.7	31.7
114 (Unhealthy for Sensitive Groups)	50	4.3	7.0
	60	4.2	6.8
	70	4.1	6.6
	80	4.0	6.5
	90	3.9	6.3
245 (Unhealthy)	50	2.0	3.2
	60	2.0	3.2
	70 to 90	1.9	3.1

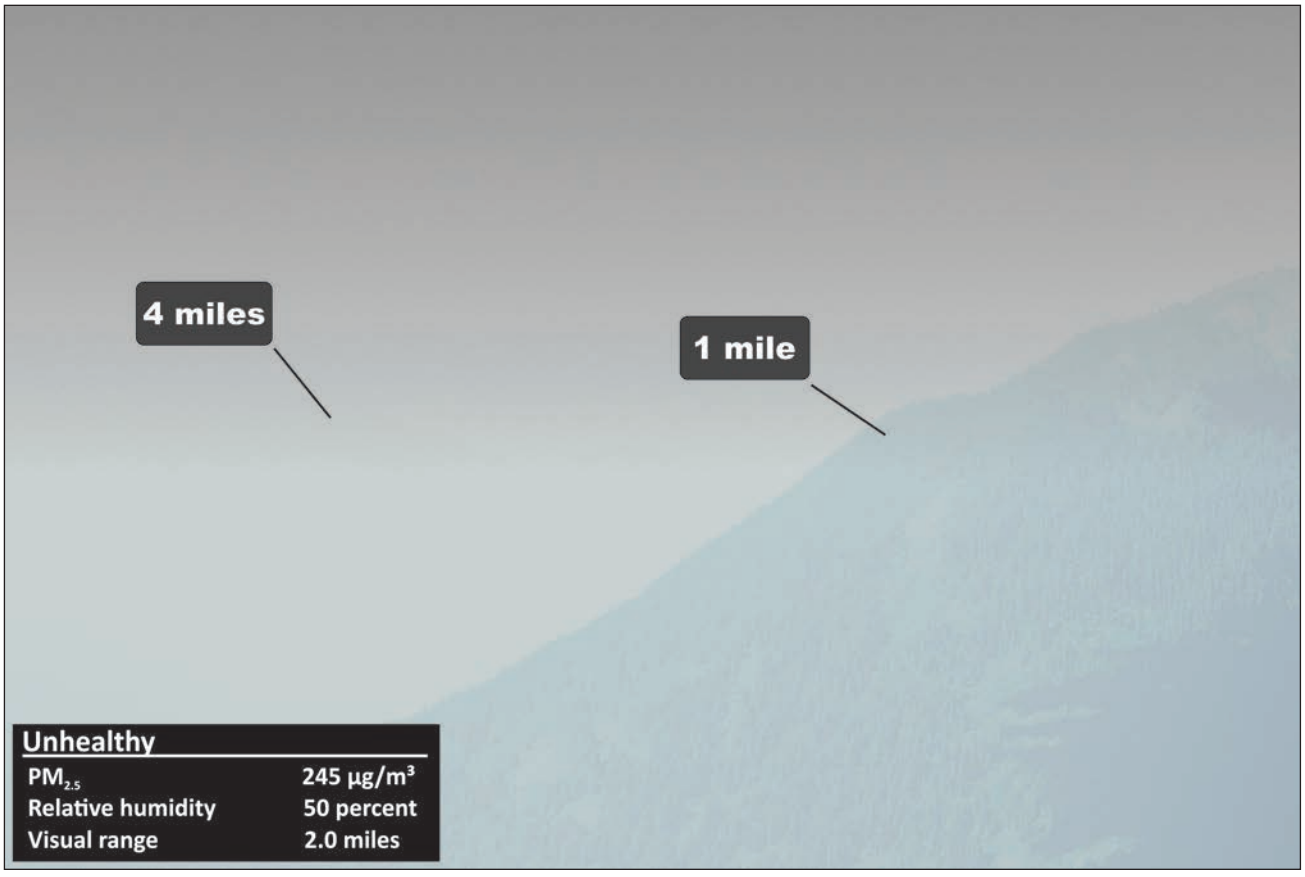
[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Snoqualmie Pass (Washington)






4 miles
1 mile
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 50 percent
Visual range 4.3 miles


4 miles
1 mile
Unhealthy
PM2.5 245 µg/m³
Relative humidity 50 percent
Visual range 2.0 miles

Southern Region (National Forest System—Region 8):
Great Smoky Mountains National Park (Tennessee)

Particulate data from 935 days (March 1988 to May 1999) at Great Smoky Mountains National Park were chosen to represent baseline and elevated regional air quality concentrations (table 18). Table 19 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<11, 19, 114, and 245 μg/m^3) and relative humidity for Great Smoky Mountains National Park. The simulated images show a baseline representing an area free from smoke-impaired visibility (<11 μg/m^3 fine and coarse particulates) and three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Great Smoky Mountains National Park (EPA 2014).

Table 18—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<11 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Great Smoky Mountains National Park, Tennessee

Particulate matter constituents	Particulate matter concentration			
	<11 (Baseline)	19	114	245
		μg/m³		
Ammonium sulfate	6.42	13.97	13.97	13.97
Ammonium nitrate	0.43	0.31	0.31	0.31
Organic carbon	2.78	3.46	92.66	215.65
Black carbon	0.47	0.23	6.03	14.04
Fine soil	0.55	1.03	1.03	1.03
Coarse mass	5.74	7.23	11.40	24.50

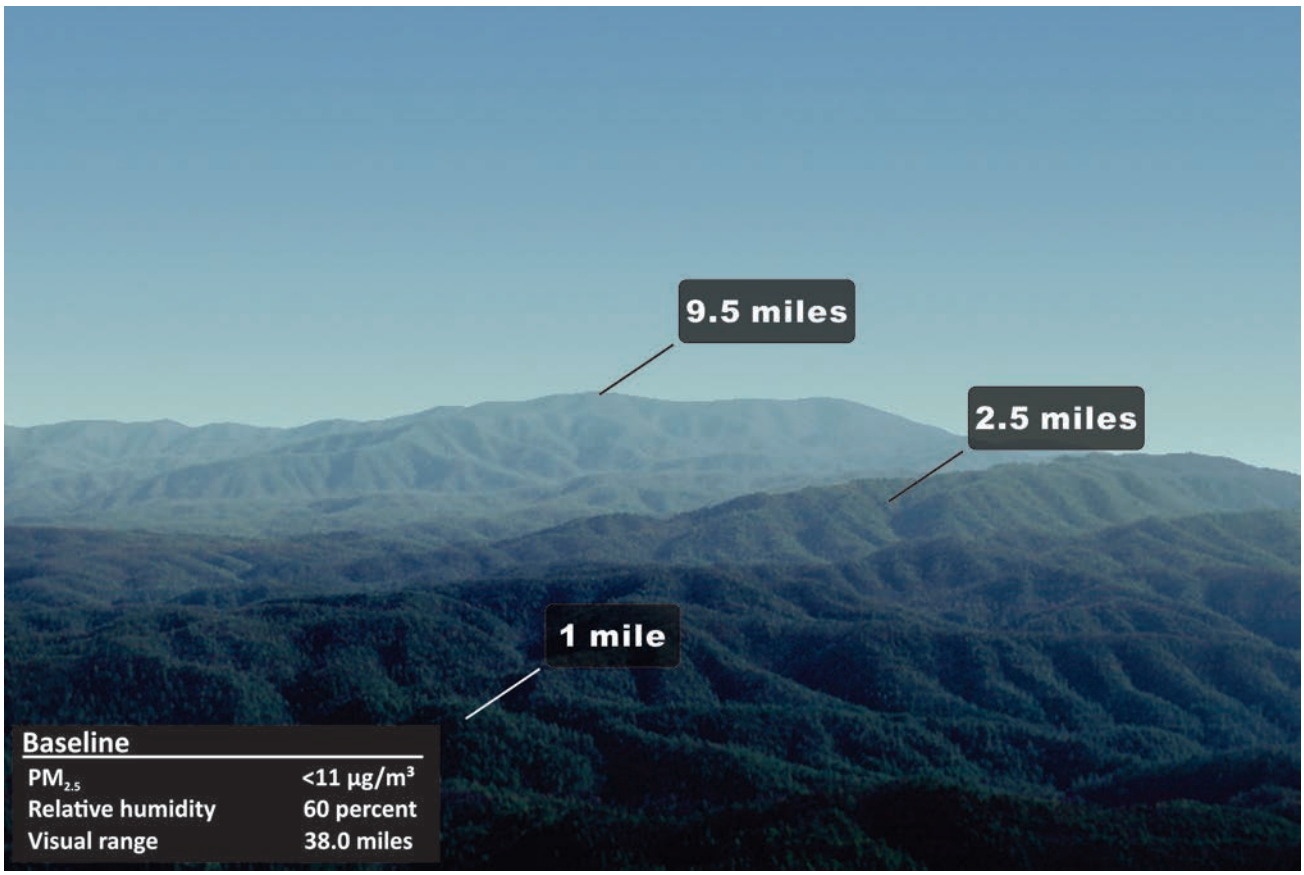
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

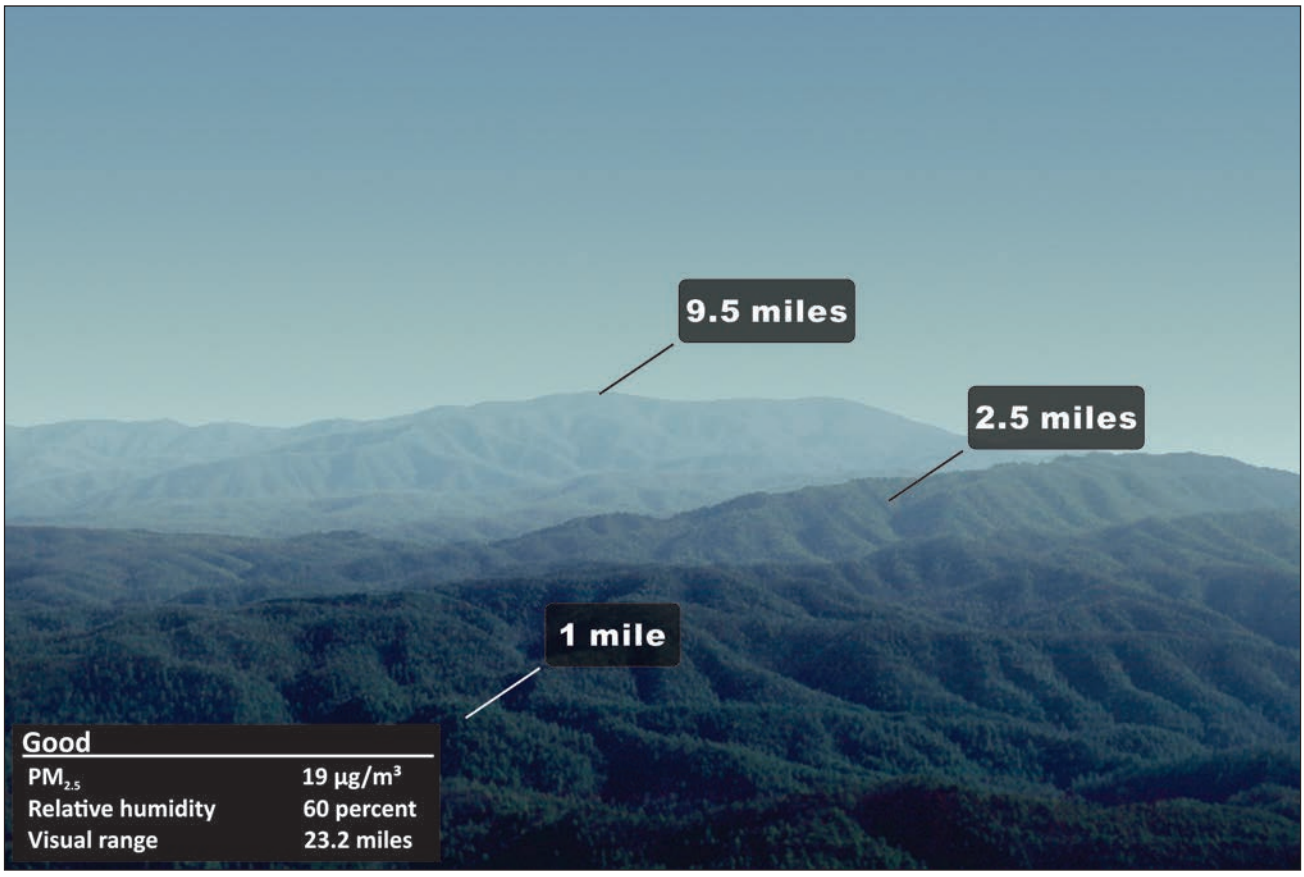
Table 19—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Great Smoky Mountains National Park, Tennessee

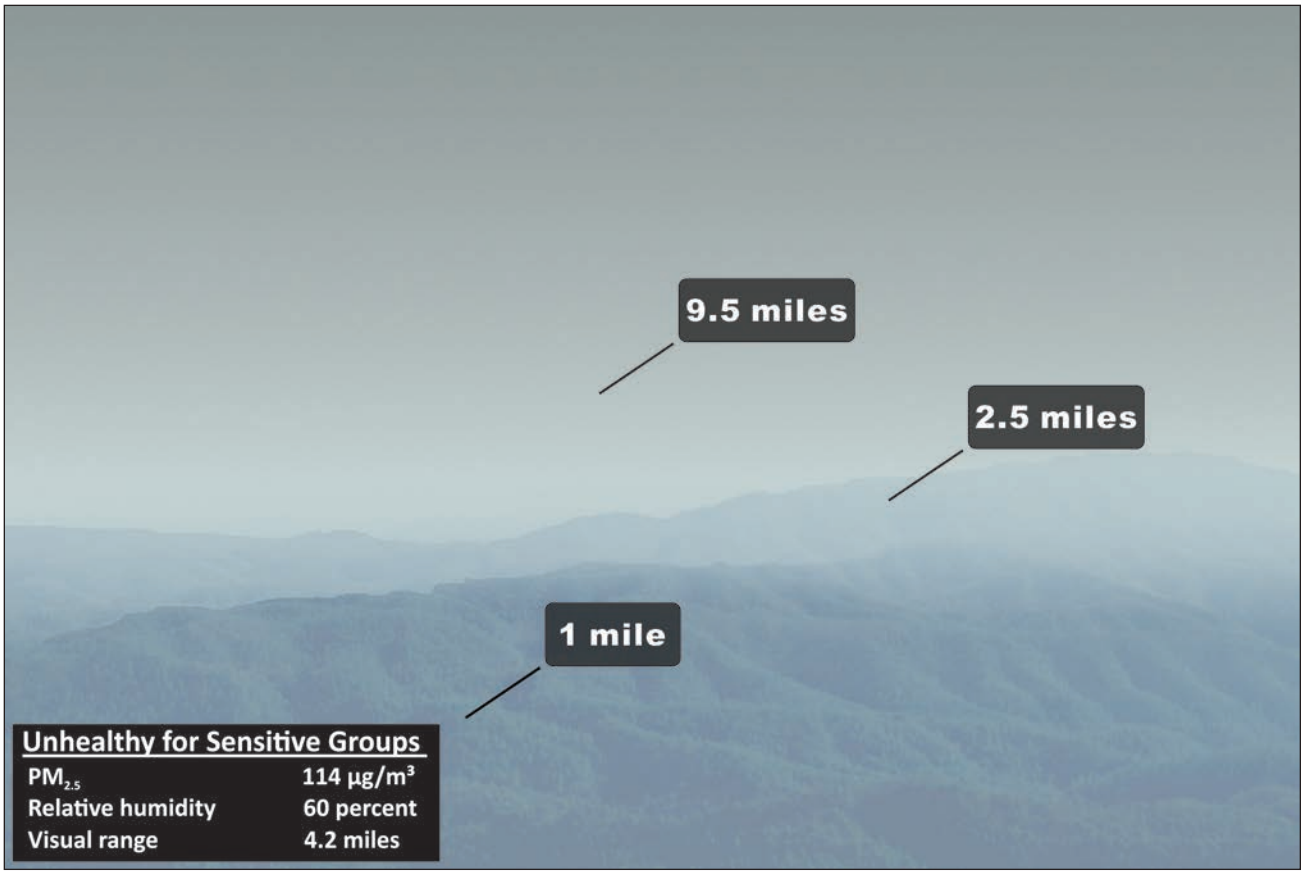
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<11 (Baseline)	60	38.0	61.2
19 (Good)	60	23.2	37.4
	70	19.6	31.5
	80	16.2	26.0
114 (Unhealthy for Sensitive Groups)	60	4.2	6.8
	70	4.0	6.5
	80	3.8	6.1
245 (Unhealthy)	60	2.0	3.2
	70	1.9	3.1
	80	1.8	2.9

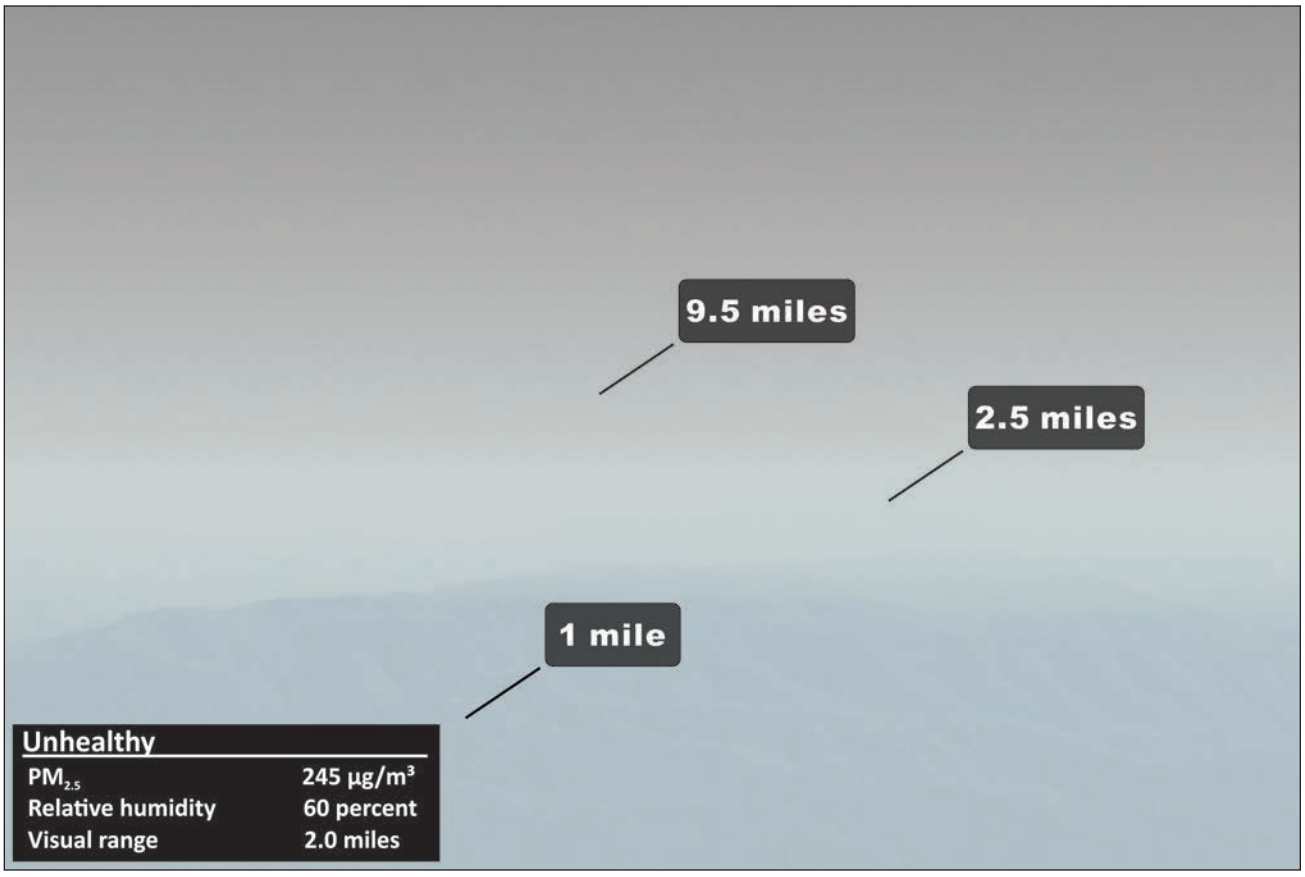
[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Great Smoky Mountains National Park (Tennessee)






9.5 miles
2.5 miles
1 mile
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 60 percent
Visual range 4.2 miles


9.5 miles
2.5 miles
1 mile
Unhealthy
PM2.5 245 µg/m³
Relative humidity 60 percent
Visual range 2.0 miles

Southern Region (National Forest System—Region 8):

Mammoth Cave National Park (Kentucky)

Particulate data from 1,067 days of sampling (October 1991 to August 2003) at Mammoth Cave National Park were chosen to represent baseline and elevated regional air quality concentrations (table 20). Table 21 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<12, 19, 114, and 245 μg/m^3) and relative humidity for Mammoth Cave National Park. The simulated images show a baseline representing an area free from smoke-impaired visibility (<12 μg/m^3 fine and coarse particulates) and three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Mammoth Cave National Park (EPA 2014).

Table 20—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<12 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Mammoth Cave National Park, Kentucky

Particulate matter constituents	Particulate matter concentration			
	<12 (Baseline)	19	114	245
		μg/m³		
Ammonium sulfate	6.94	13.99	13.99	13.99
Ammonium nitrate	0.90	0.65	0.65	0.65
Organic carbon	2.82	3.03	92.22	215.22
Black carbon	0.48	0.20	6.01	14.01
Fine soil	0.58	1.13	1.13	1.13
Coarse mass	4.43	6.26	11.40	24.50

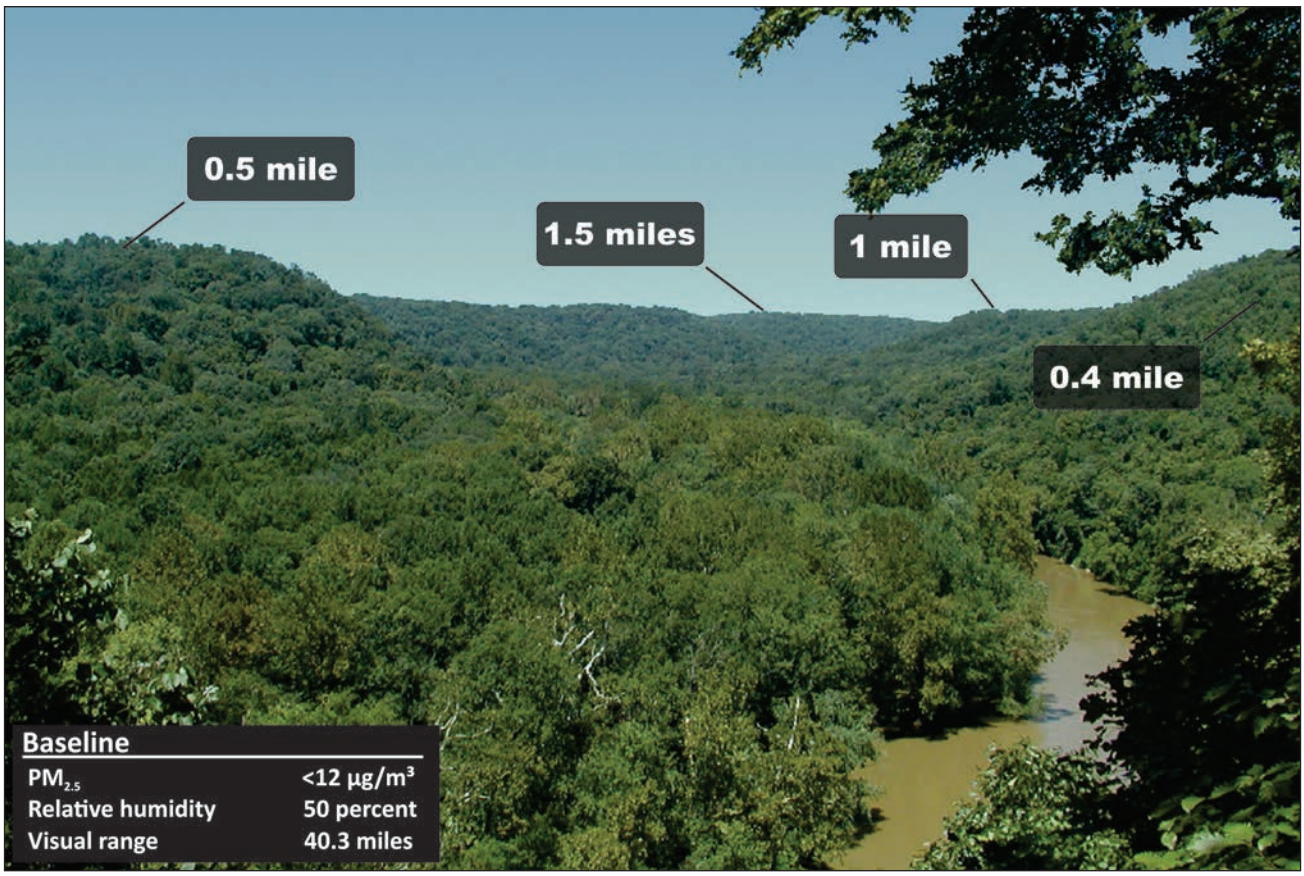
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

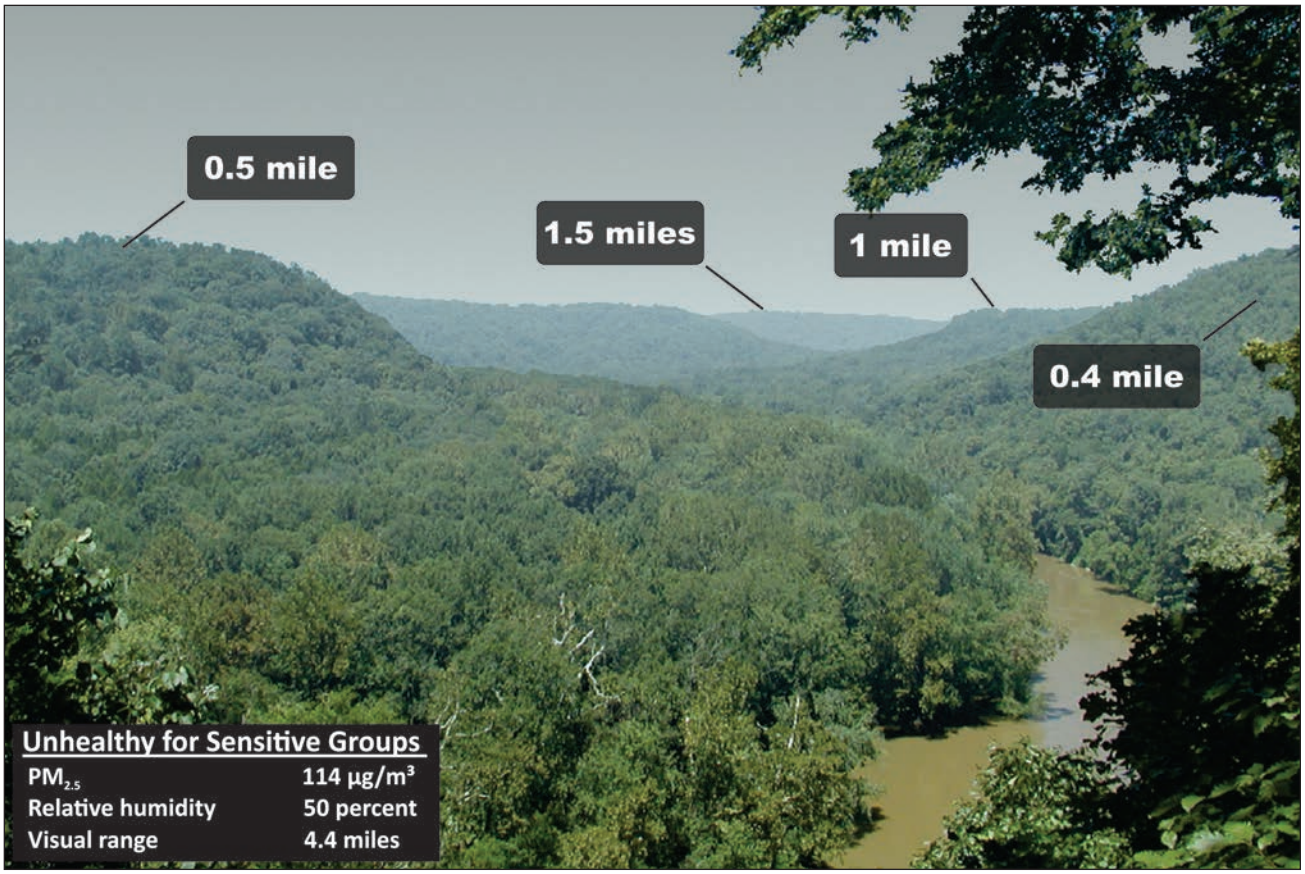
Table 21—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Mammoth Cave National Park, Kentucky

$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<12 (Baseline)	50	40.3	64.8
19 (Good	50	27.5	44.2
	60	23.4	37.7
	70	19.6	31.6
	80	16.2	26.0
114 (Unhealthy for Sensitive Groups)	50	4.4	7.1
	60	4.2	6.8
	70	4.0	6.5
	80	3.8	6.1
245 (Unhealthy)	50	2.0	3.3
	60	2.0	3.2
	70	1.9	3.1
	80	1.8	2.9

[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Mammoth Cave National Park (Kentucky)




0.5 mile
1.5 miles
1 mile
0.4 mile
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 50 percent
Visual range 4.4 miles


0.5 mile
1.5 miles
1 mile
0.4 mile
Unhealthy
PM2.5 245 µg/m³
Relative humidity 50 percent
Visual range 2.0 miles

Southern Region (National Forest System—Region 8):
Big Bend National Park (Texas)

Particulate data from 973 days of sampling (March 1988 to May 1999) at Big Bend National Park were chosen to represent baseline and elevated regional air quality concentrations (table 22). Table 23 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<6, 19, 114, and 245 μg/m^3) and relative humidity for Big Bend National Park. The simulated images show a baseline representing an area free from smoke-impaired visibility (<6 μg/m^3 fine and coarse particulates) and three levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Big Bend National Park (EPA 2014).

Table 22—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<6 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Big Bend National Park, Texas

Particulate matter constituents	Particulate matter concentration			
	<6 (Baseline)	19	114	245
		μg/m³		
Ammonium sulfate	2.47	4.31	4.31	4.31
Ammonium nitrate	0.24	0.42	0.42	0.42
Organic carbon	1.30	10.89	100.08	223.07
Black carbon	0.21	0.71	6.52	14.53
Fine soil	1.20	2.67	2.67	2.67
Coarse mass	7.69	11.82	11.82	24.50

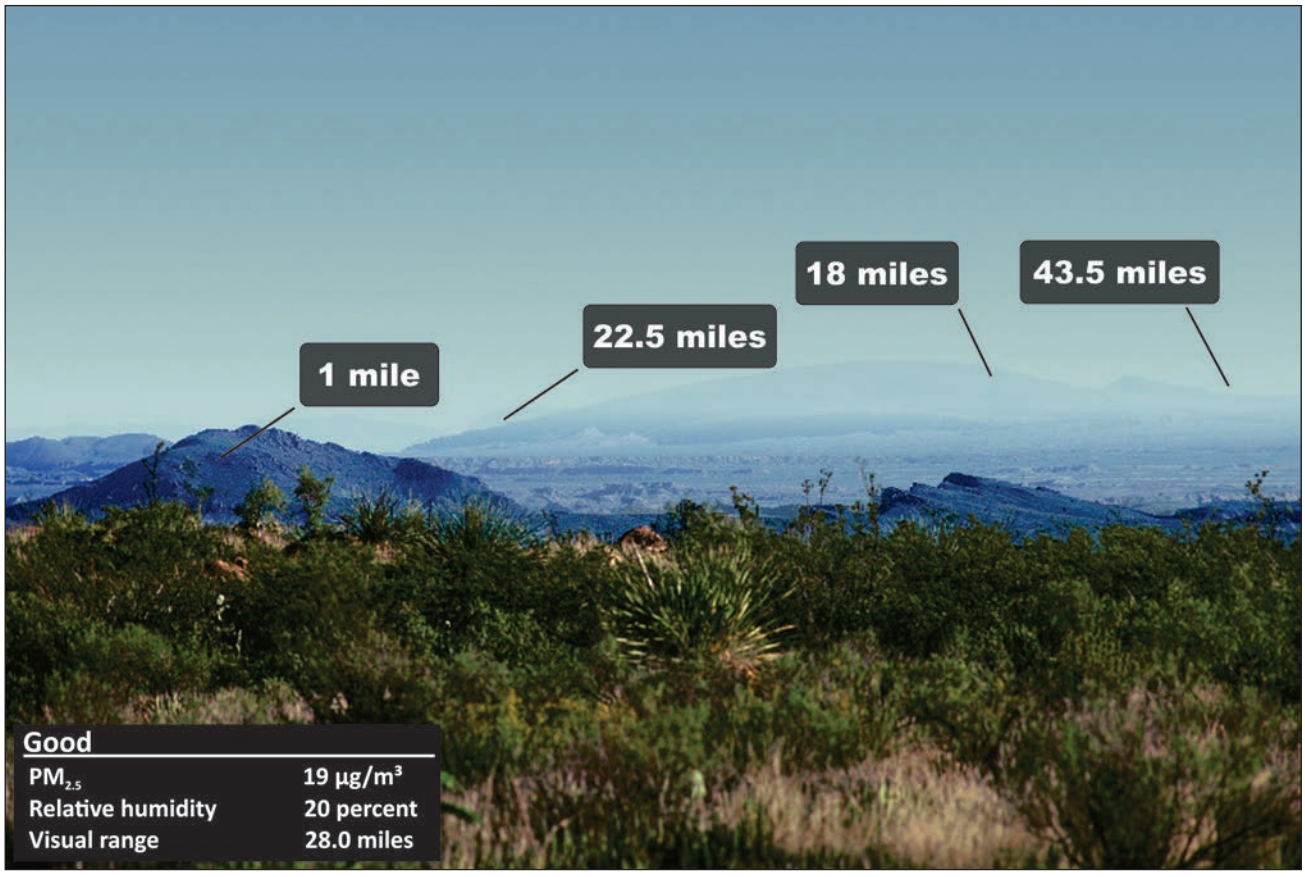
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

Table 23—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Big Bend National Park, Texas

$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<6 (Baseline)	20	77.7	125.0
19 (Good)	20	28.0	45.1
	30	27.7	44.5
	40	27.0	43.5
	50	25.7	41.3
	60	24.2	38.9
	70	22.5	36.2
114 (Unhealthy for Sensitive Groups)	20	4.7	7.5
	30	4.6	7.4
	40	4.5	7.2
	50	4.4	7.1
	60	4.3	6.9
	70	4.2	6.7
245 (Unhealthy)	20	2.2	3.5
	30 to 40	2.1	3.4
	50 to 60	2.0	3.2
	70	1.9	3.1

[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Big Bend National Park (Texas)




1 mile
22.5 miles
18 miles
43.5 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m³
Relative humidity 20 percent
Visual range 4.7 miles


1 mile
22.5 miles
18 miles
43.5 miles
Unhealthy
PM2.5 245 µg/m³
Relative humidity 20 percent
Visual range 2.2 miles

Eastern Region (National Forest System—Region 9):
Acadia National Park (Maine)

Particulate data from 986 days of sampling (March 1988 to May 1999) at Acadia National Park were chosen to represent baseline and elevated regional air quality concentrations (table 24). Table 25 shows the simulated visual range at different levels of $PM_{2.5}$ concentration (<6, 19, 114, and 245 μg/m^3) and relative humidity for Acadia National Park. The simulated images show a baseline representing an area free from smoke-impaired visibility (<6 μg/m^3 fine and coarse particulates) and two levels of impairment (table 1). Data used for estimating the effect of relative humidity on visual range during the May to September fire season are from Acadia National Park (EPA 2014).

Table 24—Constituents of particulate matter ($PM_{2.5}$ and PM_{10}) at baseline (<6 μg/m^3) and elevated (19, 114, and 245 μg/m^3) levels in Acadia National Park, Maine

Particulate matter constituents	Particulate matter concentration			
	<6 (Baseline)	19	114	245
		μg/m³		
Ammonium sulfate	3.07	6.83	6.83	6.83
Ammonium nitrate	0.37	0.71	0.71	0.71
Organic carbon	1.59	10.42	99.61	222.60
Black carbon	0.34	0.68	6.49	14.50
Fine soil	0.22	0.36	0.36	0.36
Coarse mass	4.66	5.78	11.40	24.50

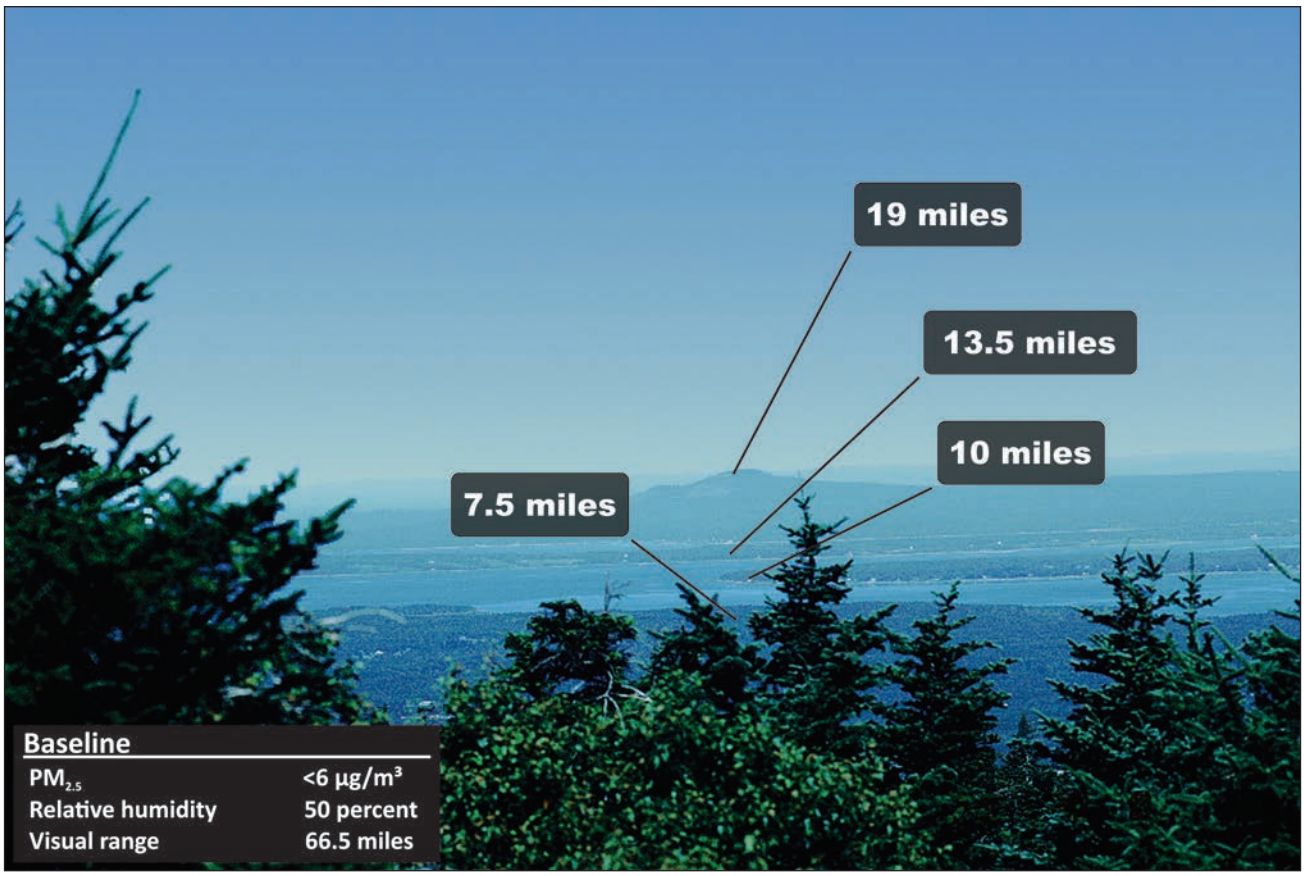
Note: PM_{10} and $PM_{2.5}$ are composed of particles that are ≤10 μm and ≤2.5 μm in diameter, respectively.

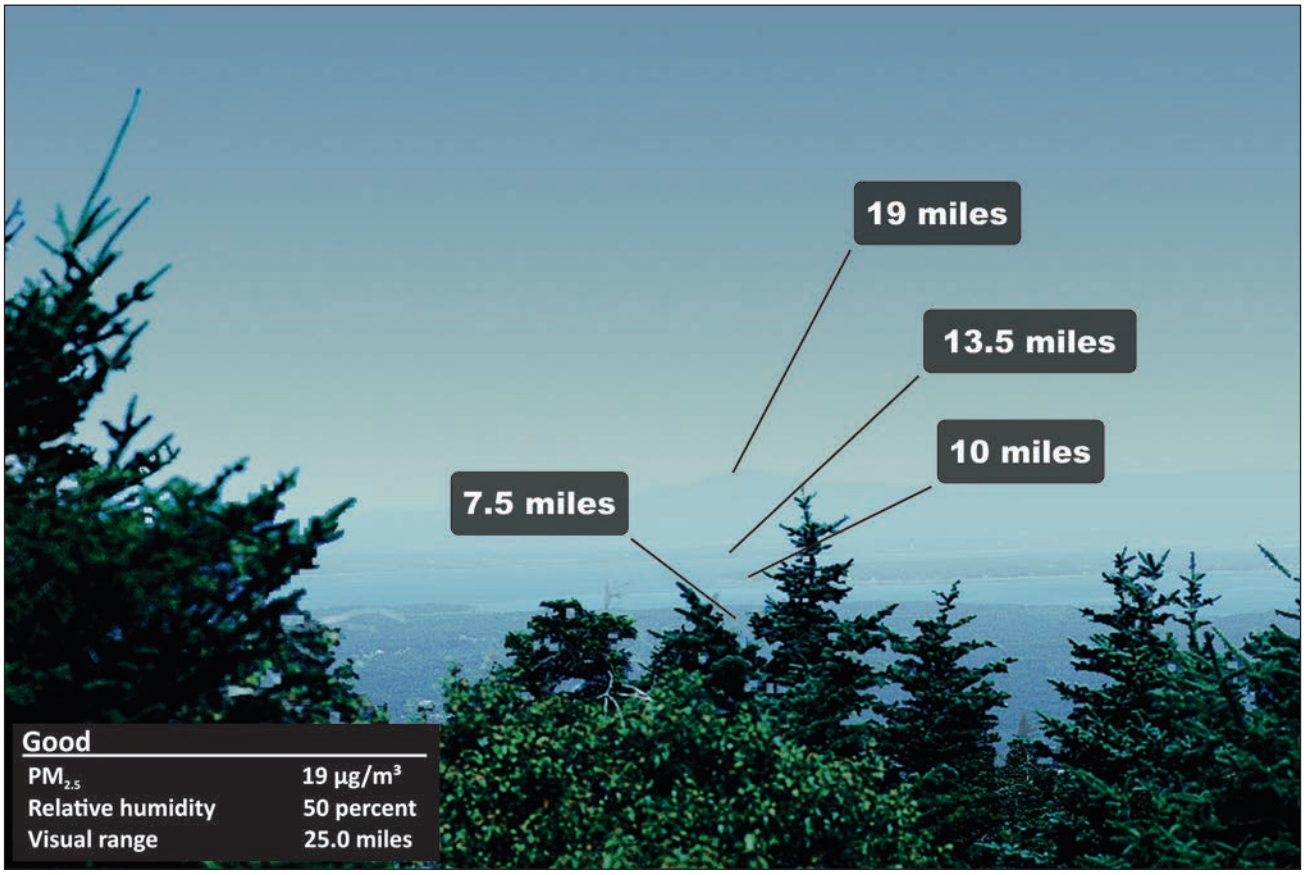
Table 25—Simulated visual range as a function of $PM_{2.5}$ concentration ($\mu g/m^3$) and relative humidity in Acadia National Park, Maine

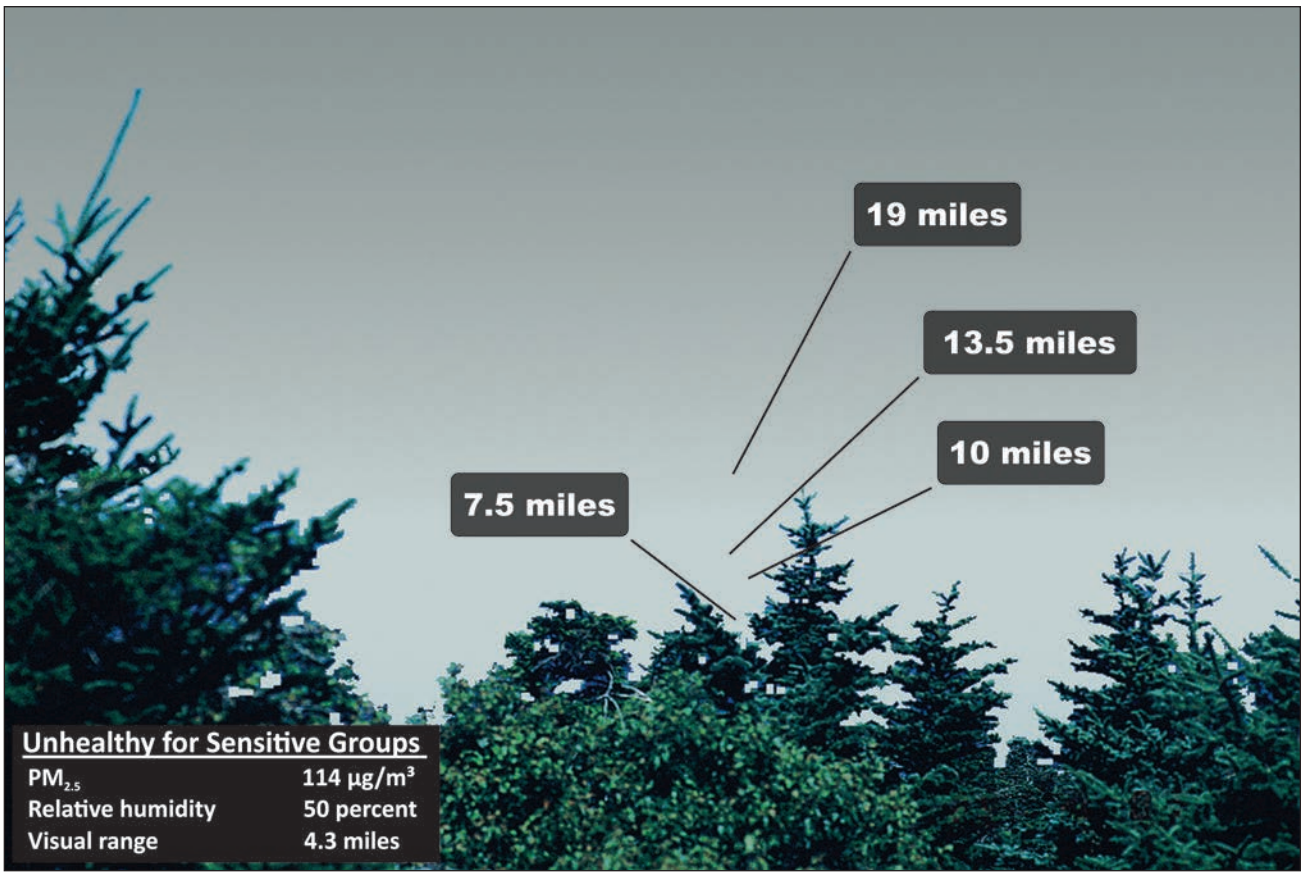
$PM_{2.5}$ concentration[a]	Relative humidity	Visual range	
	Percent	*Miles*	*Kilometers*
<6 (Baseline)	50	66.5	107.0
19 (Good)	50	25.0	40.2
	60	22.9	36.9
	70	20.7	33.3
	80	18.4	29.6
114 (Unhealthy for Sensitive Groups)	50	4.3	7.0
	60	4.2	6.8
	70	4.1	6.5
	80	3.9	6.3
245 (Unhealthy)	50 to 60	1.9	3.1
	70	1.8	2.9
	80	1.7	2.7

[a] $PM_{2.5}$ is composed of particles that are ≤2.5 μm in diameter.

Acadia National Park (Maine)






19 miles
13.5 miles
10 miles
7.5 miles
Unhealthy for Sensitive Groups
PM2.5 114 µg/m3
Relative humidity 50 percent
Visual range 4.3 miles

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